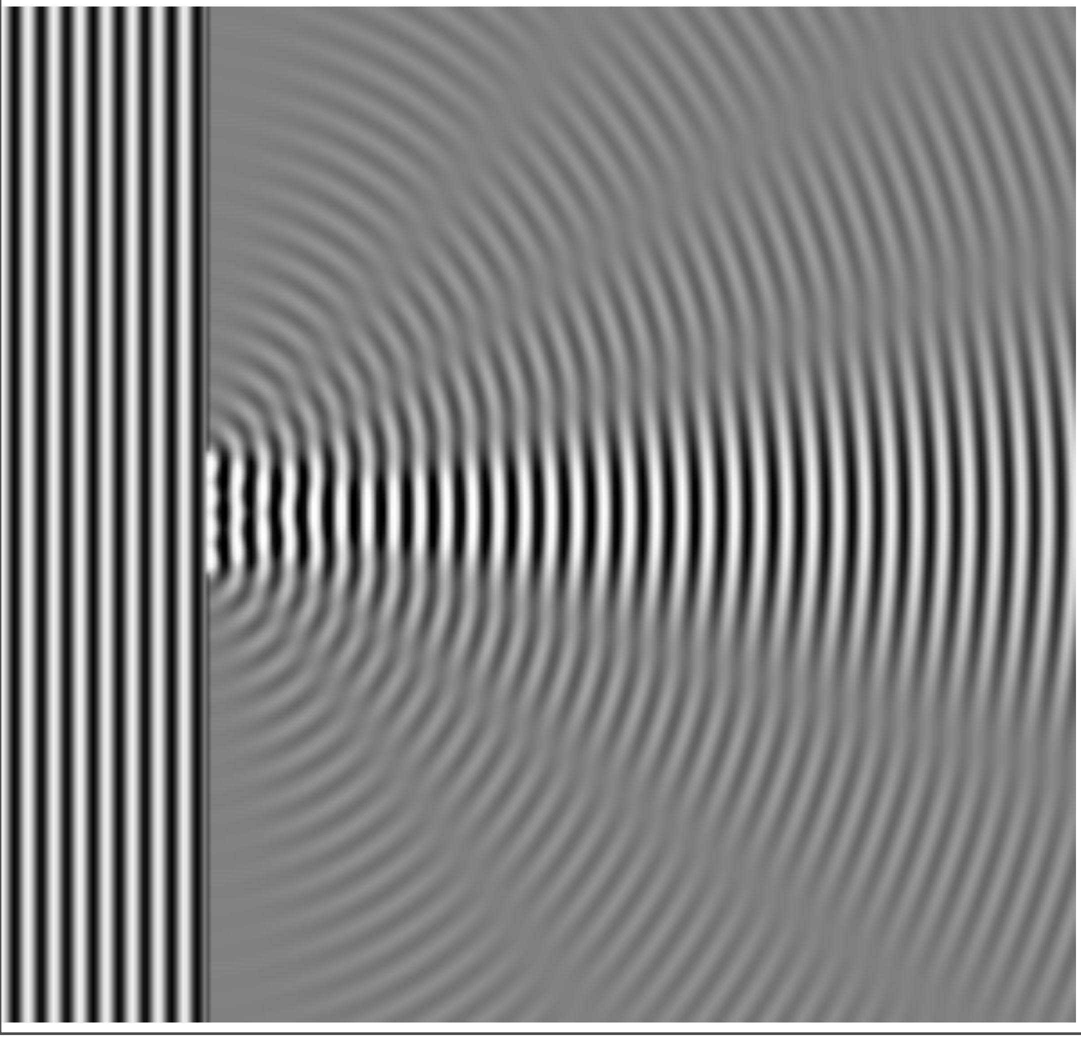
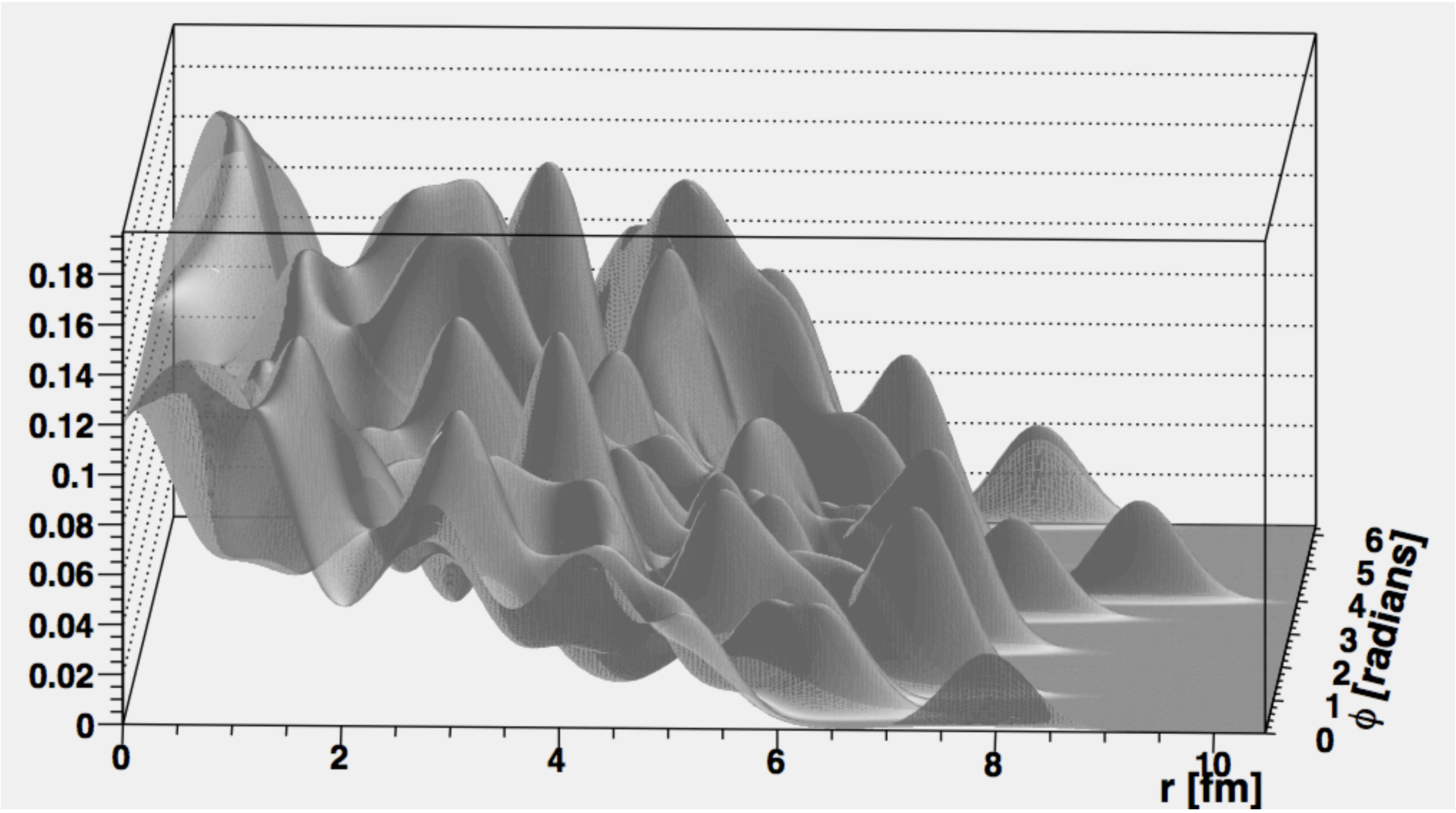
eRHIC

Understanding the initial condition of the heavy ion

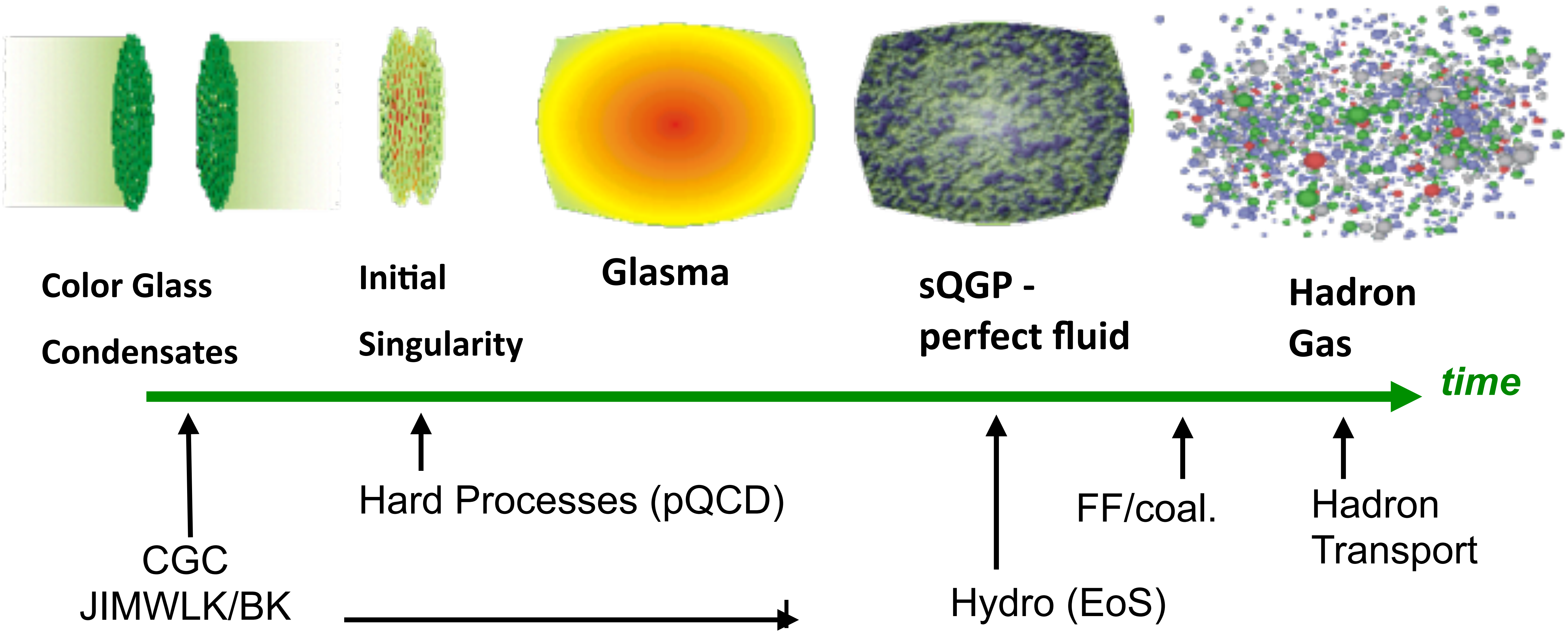
2012 RHIC & AGS Annual Users' Meeting

Tobias Toll





“Standard model of Heavy Ion Collisions”



Our understanding of some fundamental properties of the Glasma, sQGP and Hadron Gas depend strongly on our knowledge of the initial state!

3 conundrums of the initial state:

1. What is the spatial transverse distributions of gluons?
2. How much does the spatial distribution fluctuate? Lumpiness, hot-spots etc.
3. How saturated is the initial state of the nucleus?

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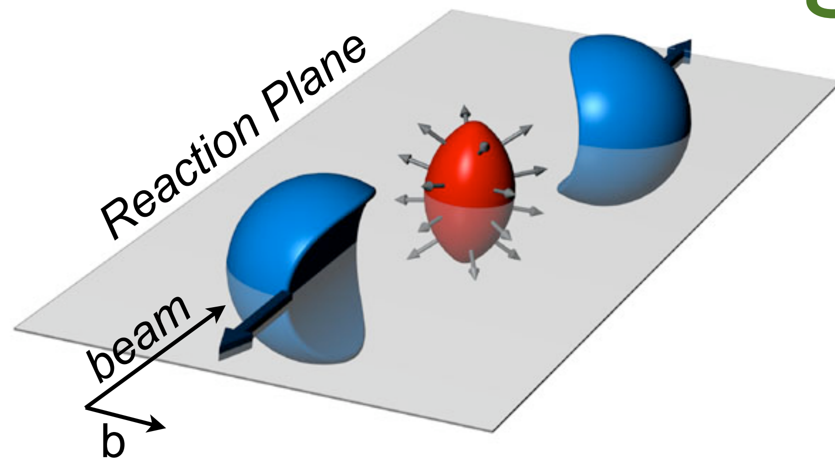
Different initial distributions gives different flows!

$$\epsilon_2 = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



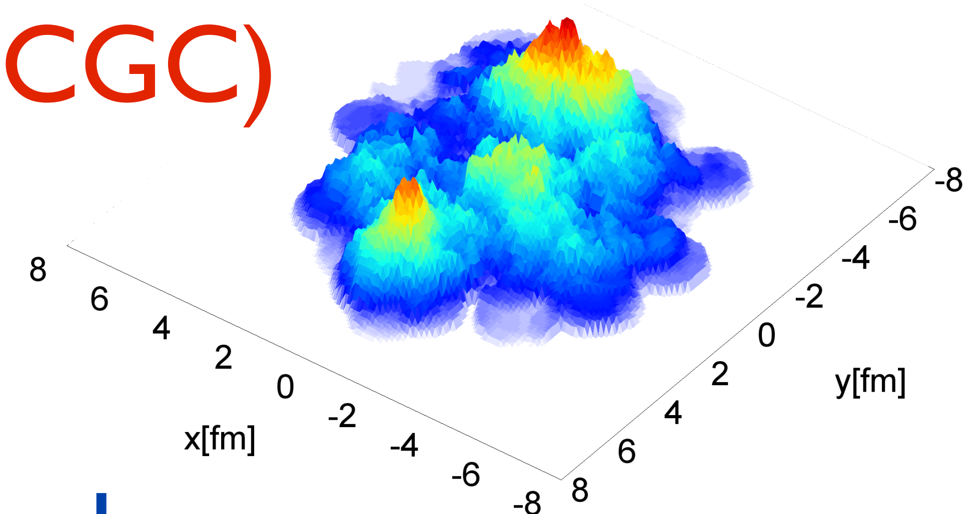
The question is what is ε?

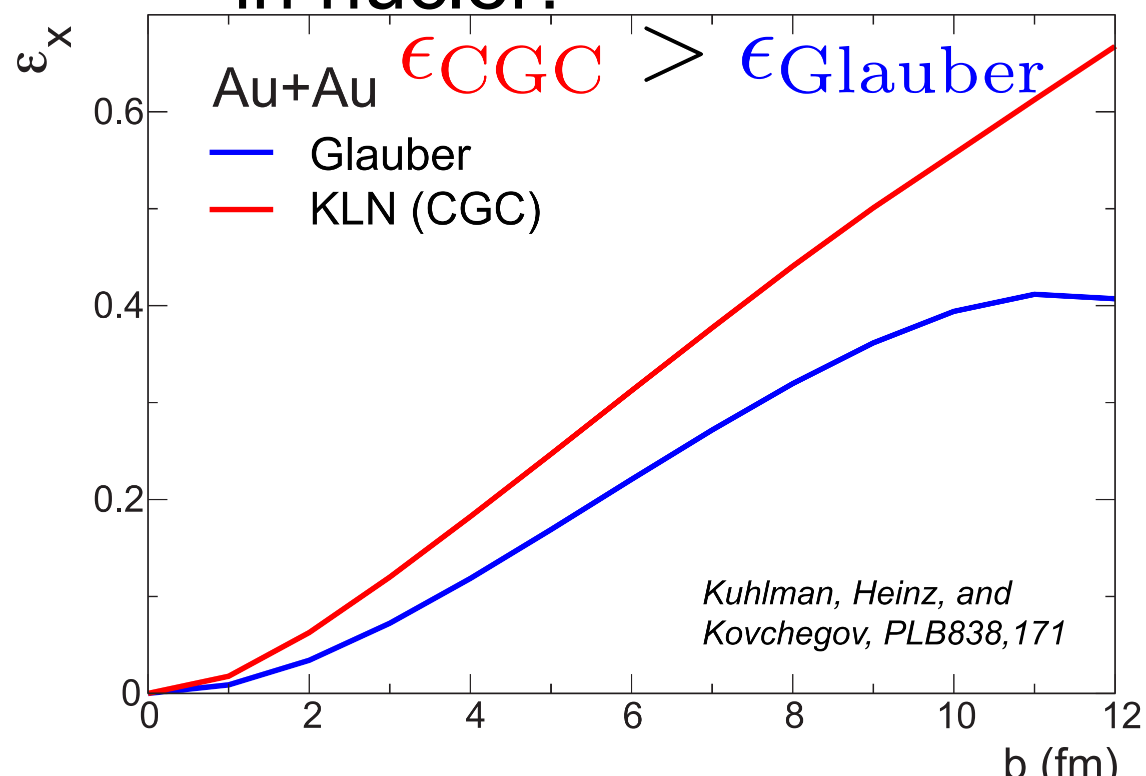
RHIC & LHC: low-p_T realm driven almost entirely by glue ⇒ spatial distribution of glue in nuclei?

Two methods for ε:

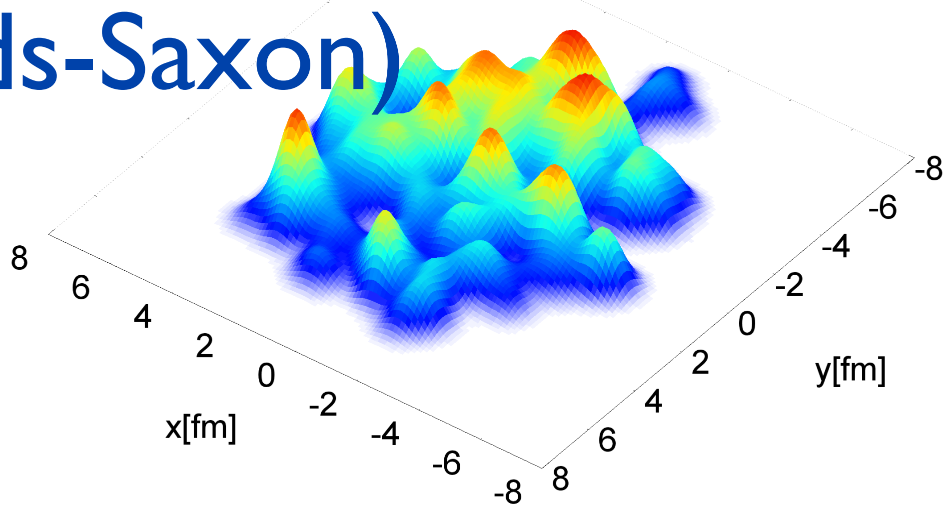
- Glauber (non-saturated)?
- CGC (saturated)?

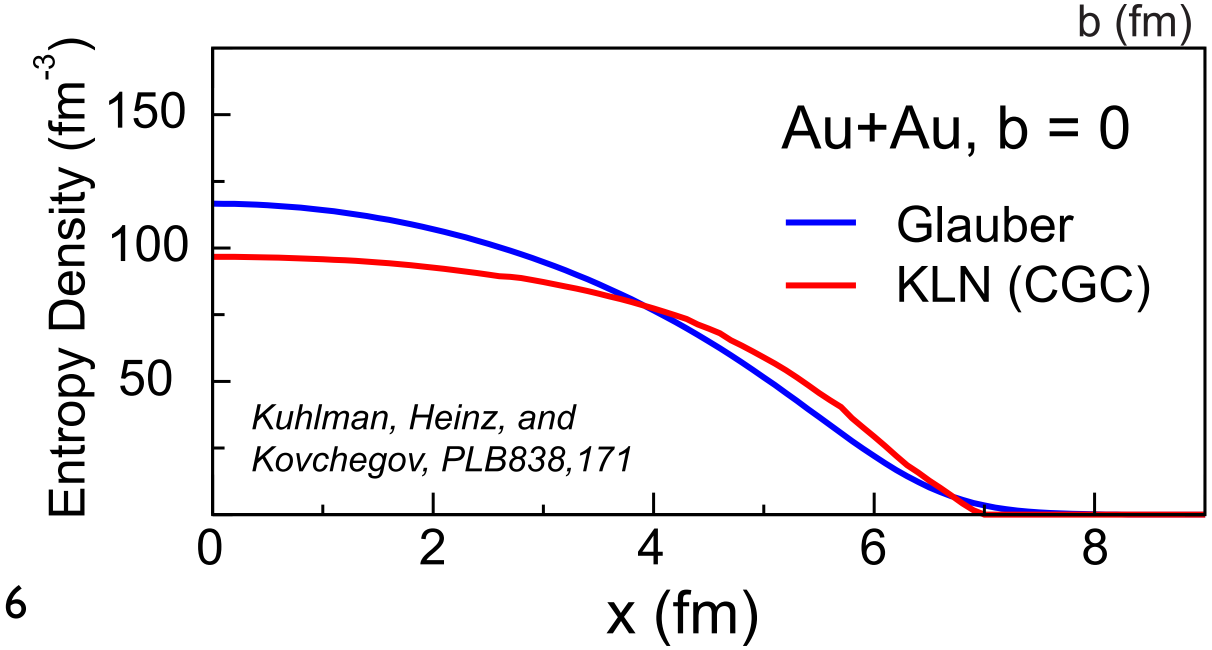
KLN(CGC)





Glauber (Woods-Saxon)





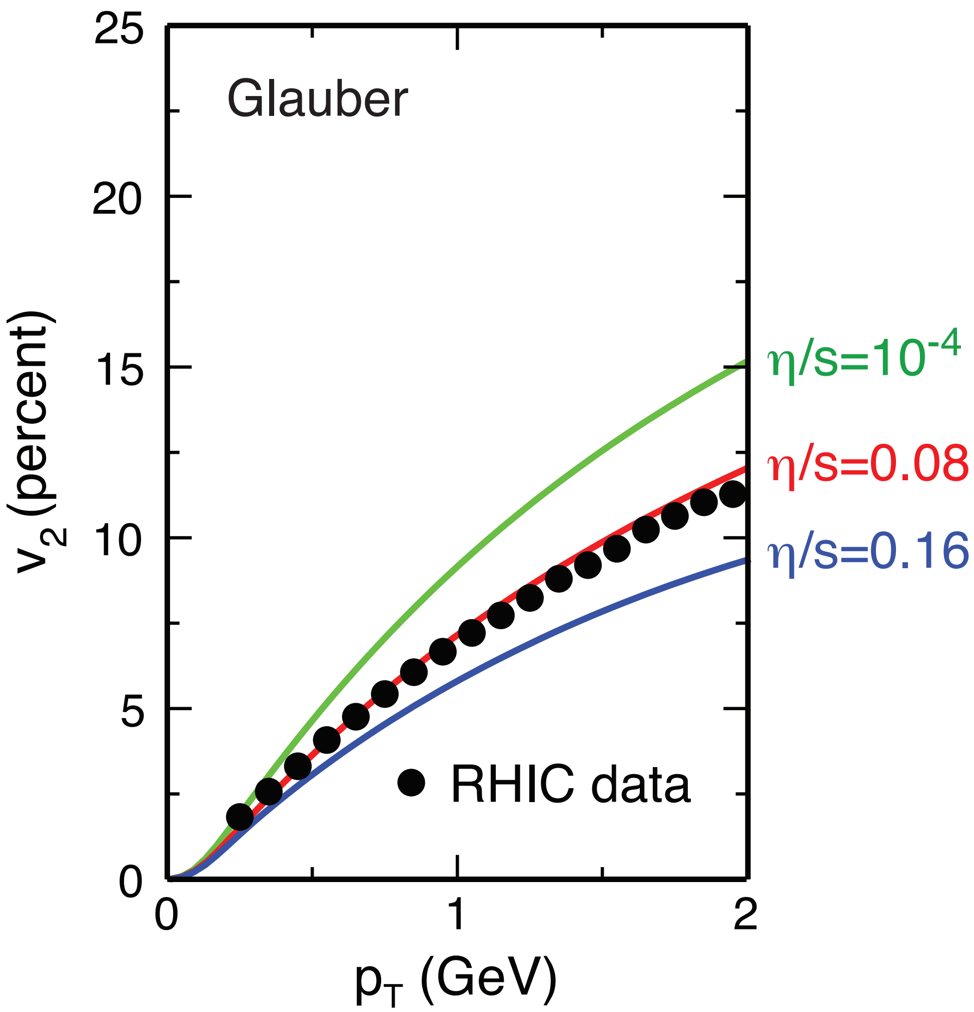
Is the sQGP a perfect fluid?

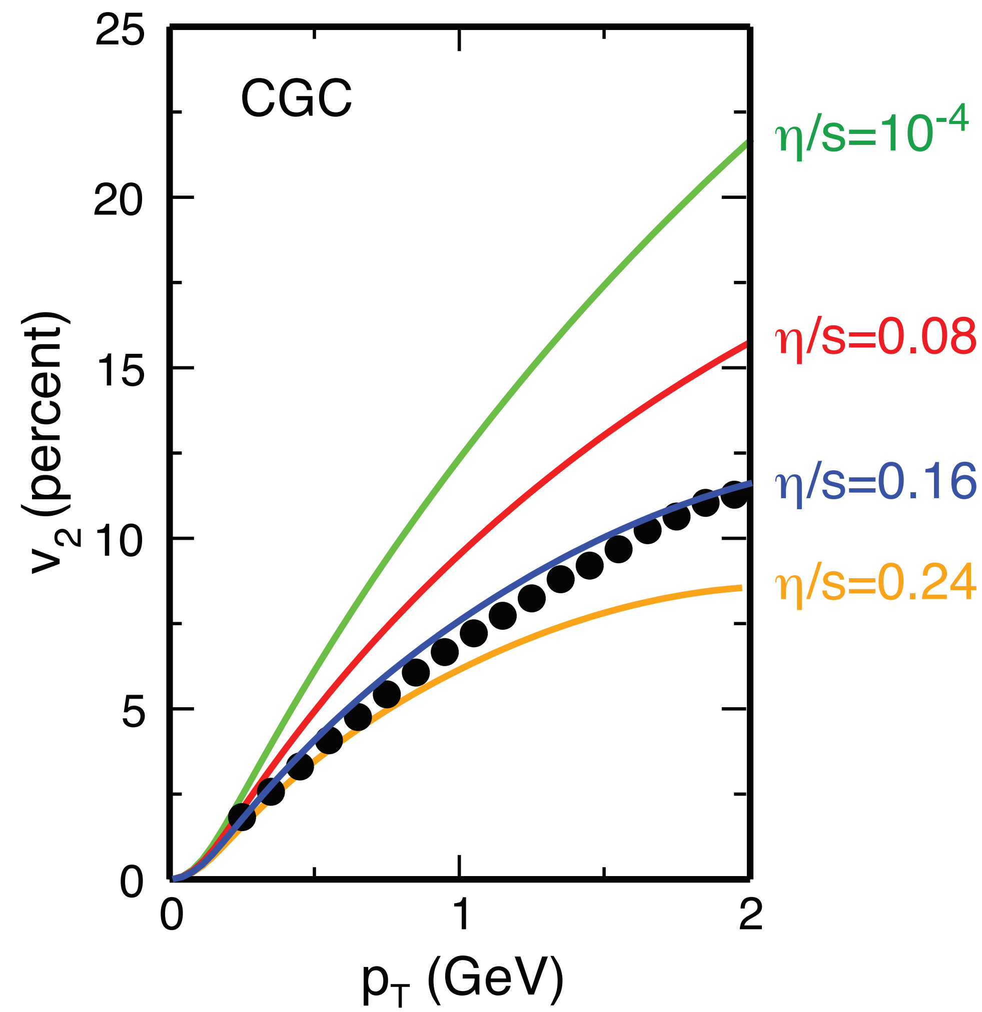
AdS/CFT predicts for a perfect fluid:

$\eta/s = 1/(4\pi) \sim 0.08$

Different initial geometries of nuclei gives different η/s of the strongly coupled Quark-Gluon Plasma

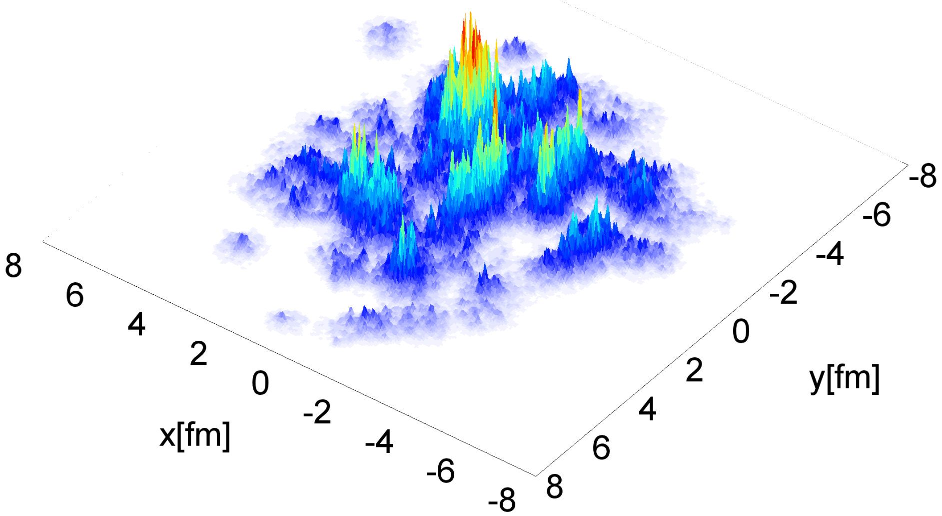
How "perfect" is the fluid?





Is the sQGP a perfect fluid?

IP-Gl



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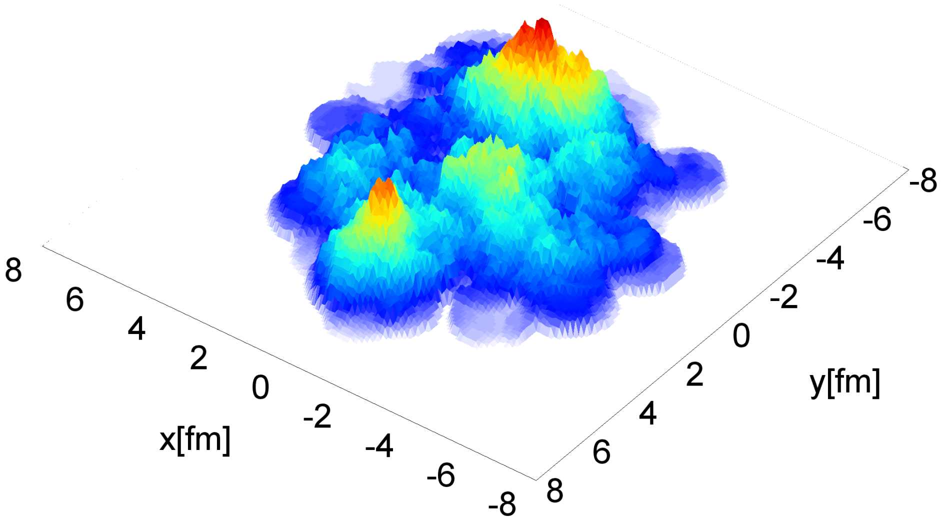
KLN(



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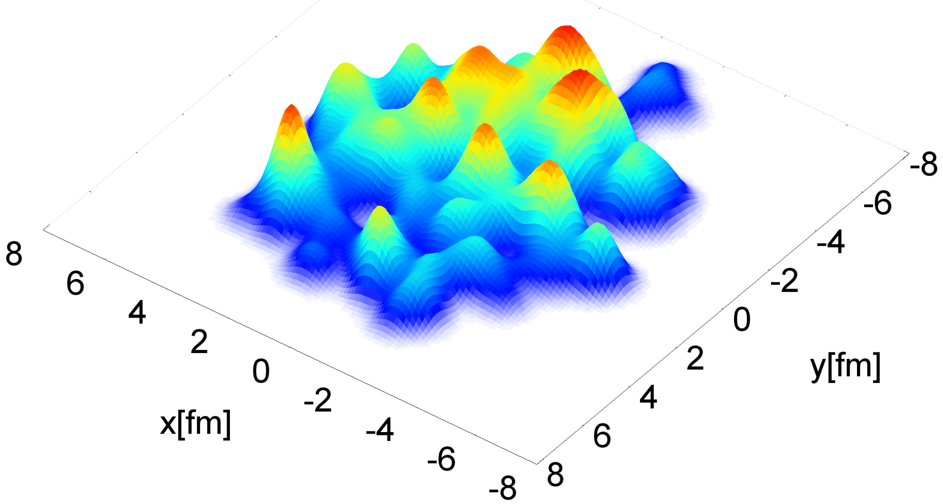
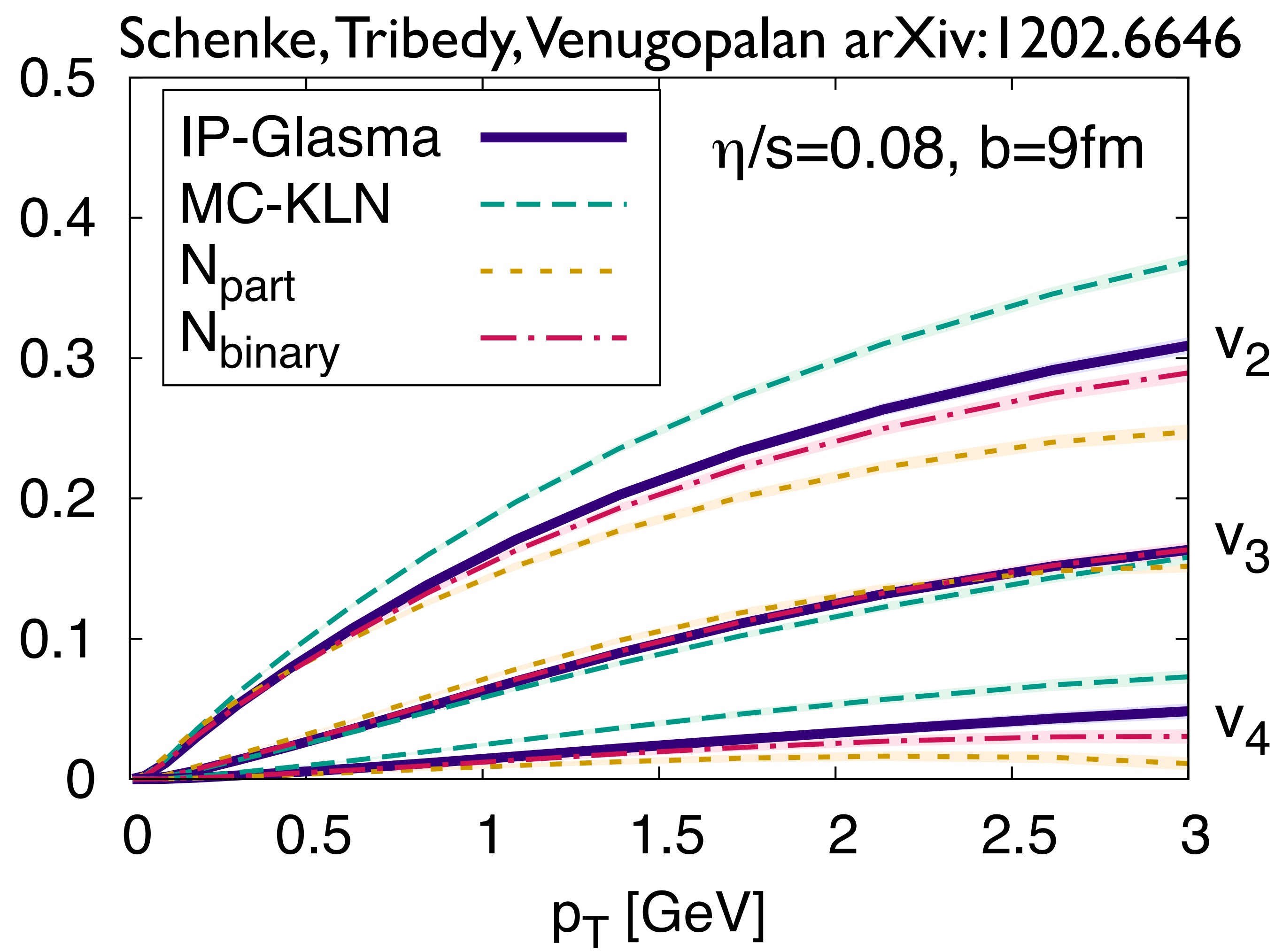


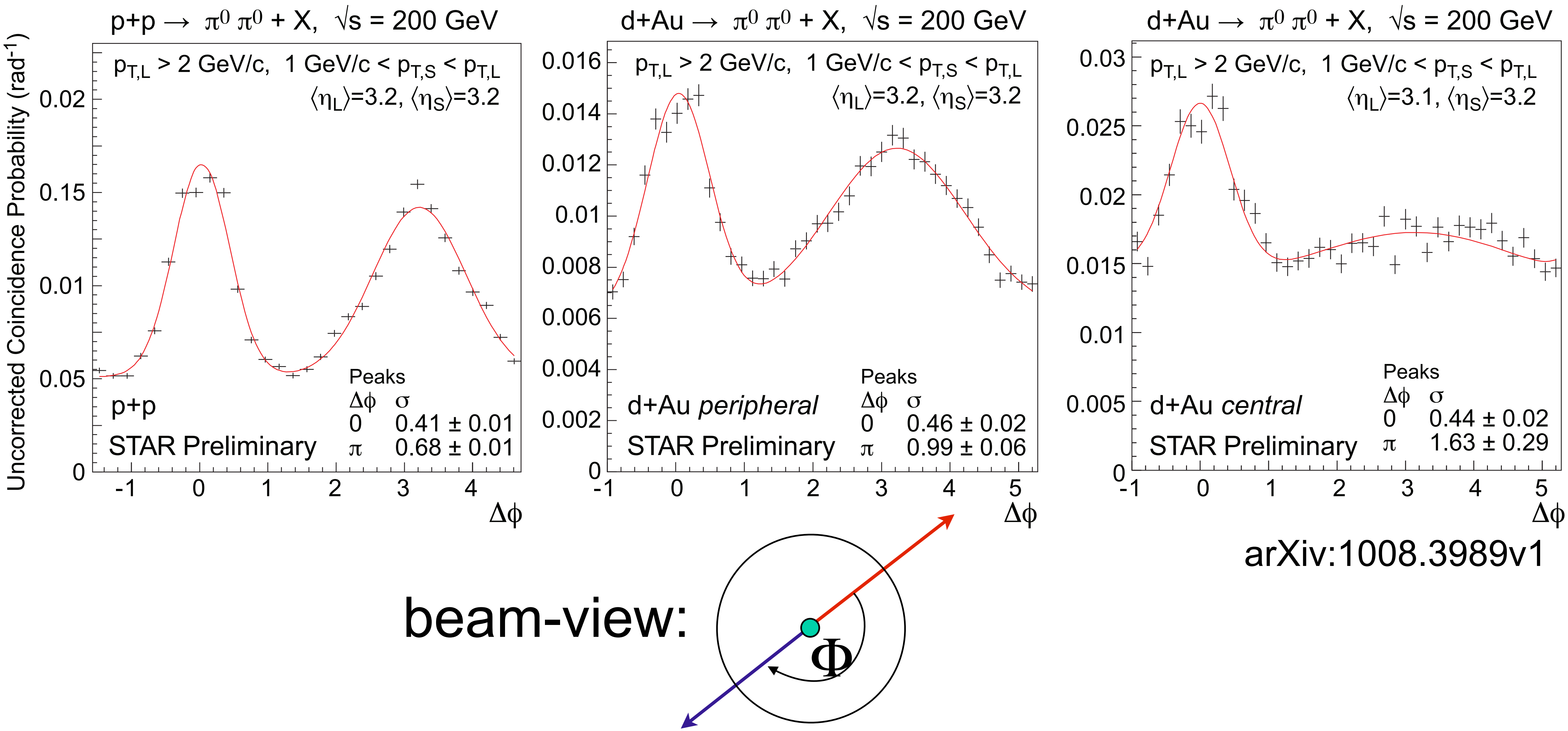


Different initial states=
different fluctuation scales

3 conundrums of the initial state:

1. What is the spatial transverse distributions of nucleons and gluons?
2. How much does the spatial distribution fluctuate? Lumpiness, hot-spots etc.
3. How saturated is the initial state of the nucleus?

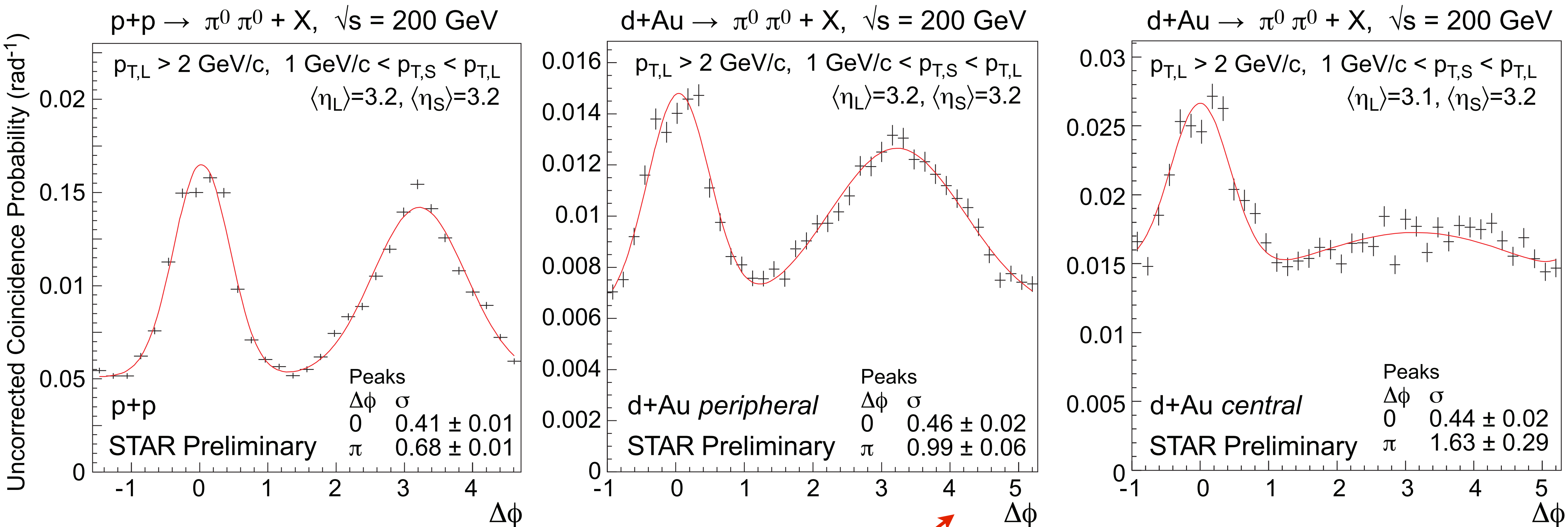
π^0-π^0 forward correlation in *pp* and *dA* at RHIC



arXiv:1008.3989v1

Striking broadening of away side peak in central *dA* compared to *pp* and peripheral *dA*!

π^0-π^0 forward correlation in *pp* and *dA* at RHIC



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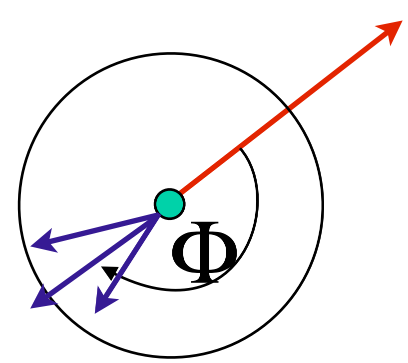
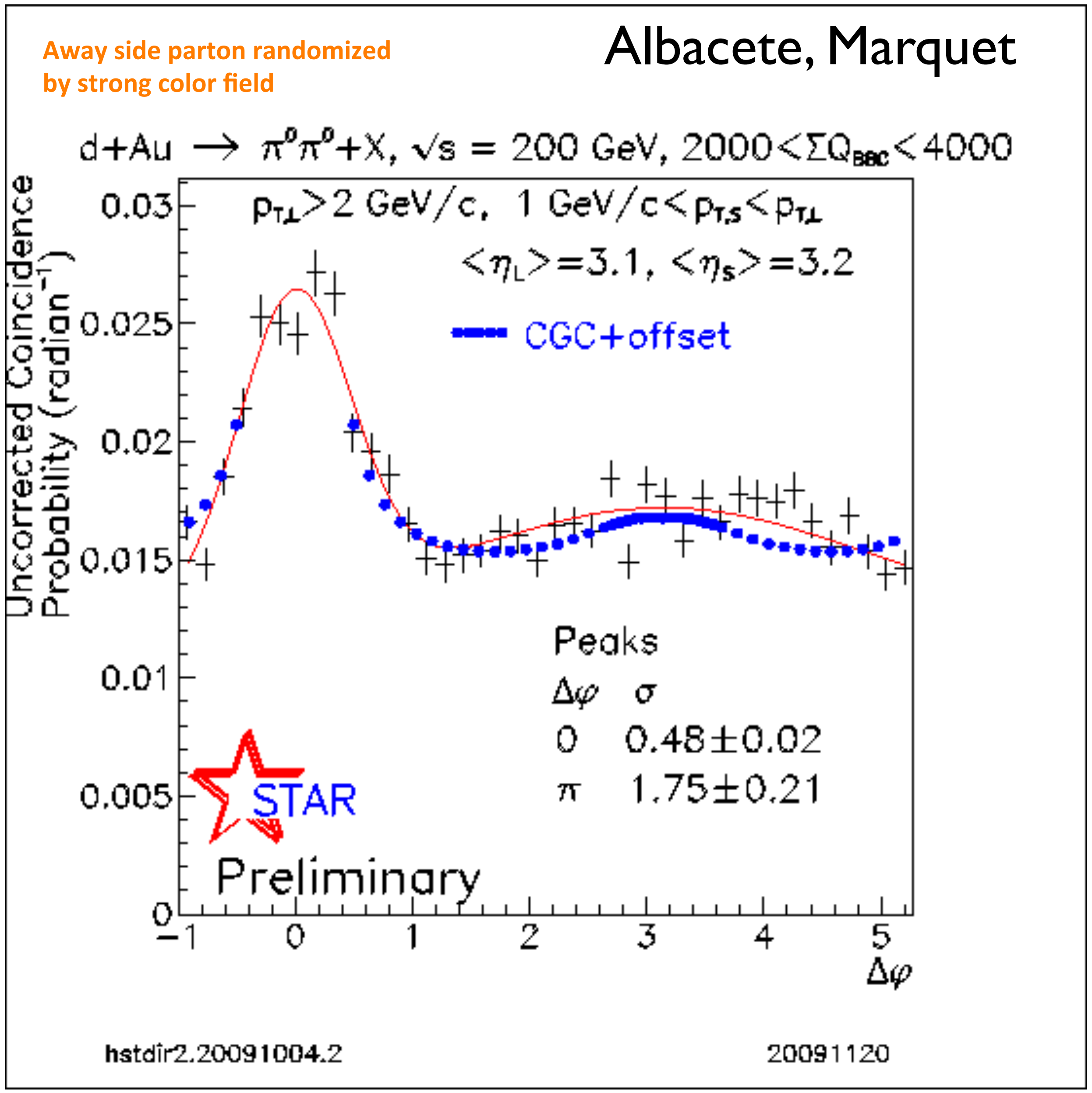
beam-view:



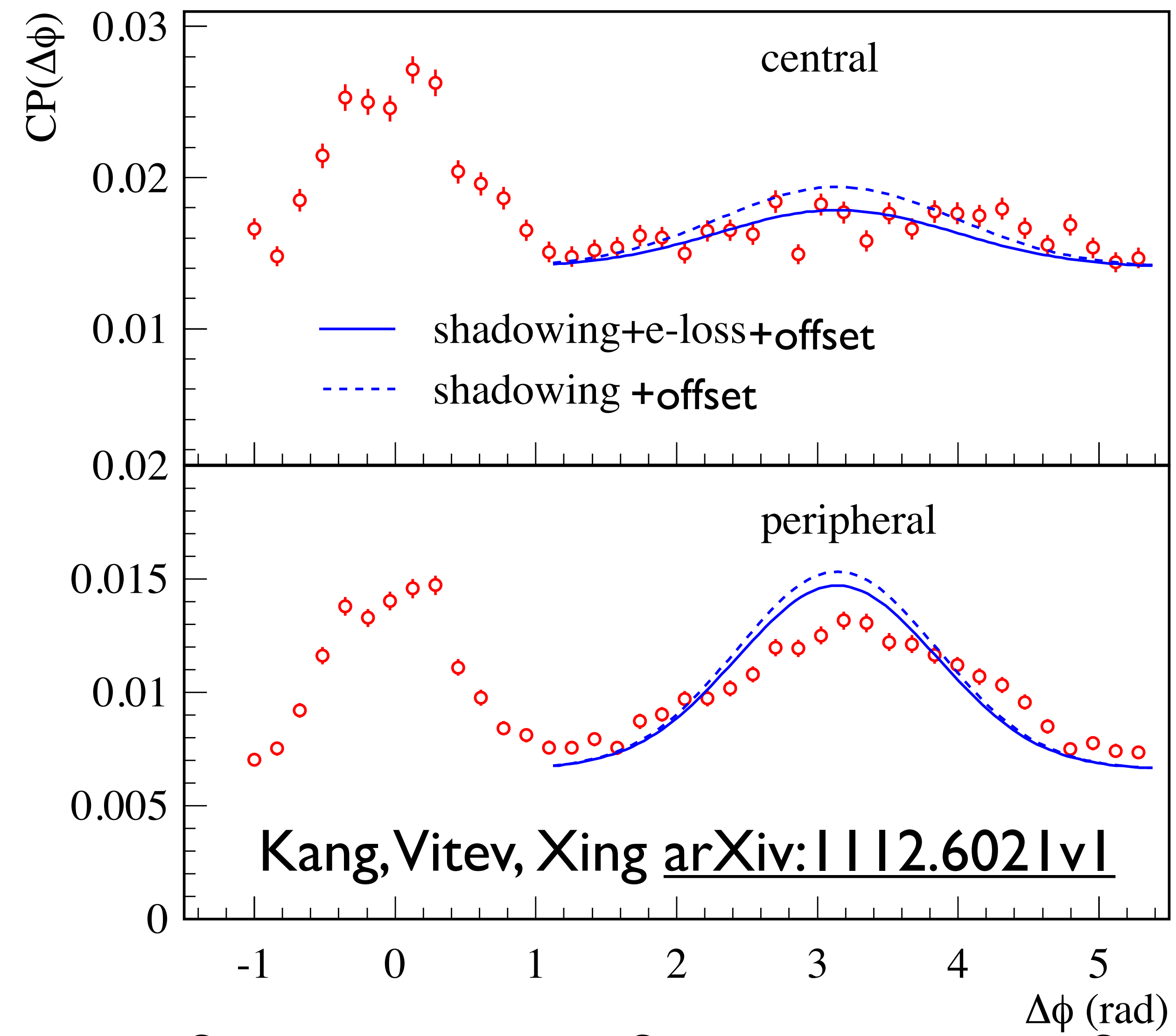
Striking broadening of away side peak in central *dA* compared to *pp* and peripheral *dA*!

1 question, 2 answers

Initial state saturation model



Initial and final state multiple scattering

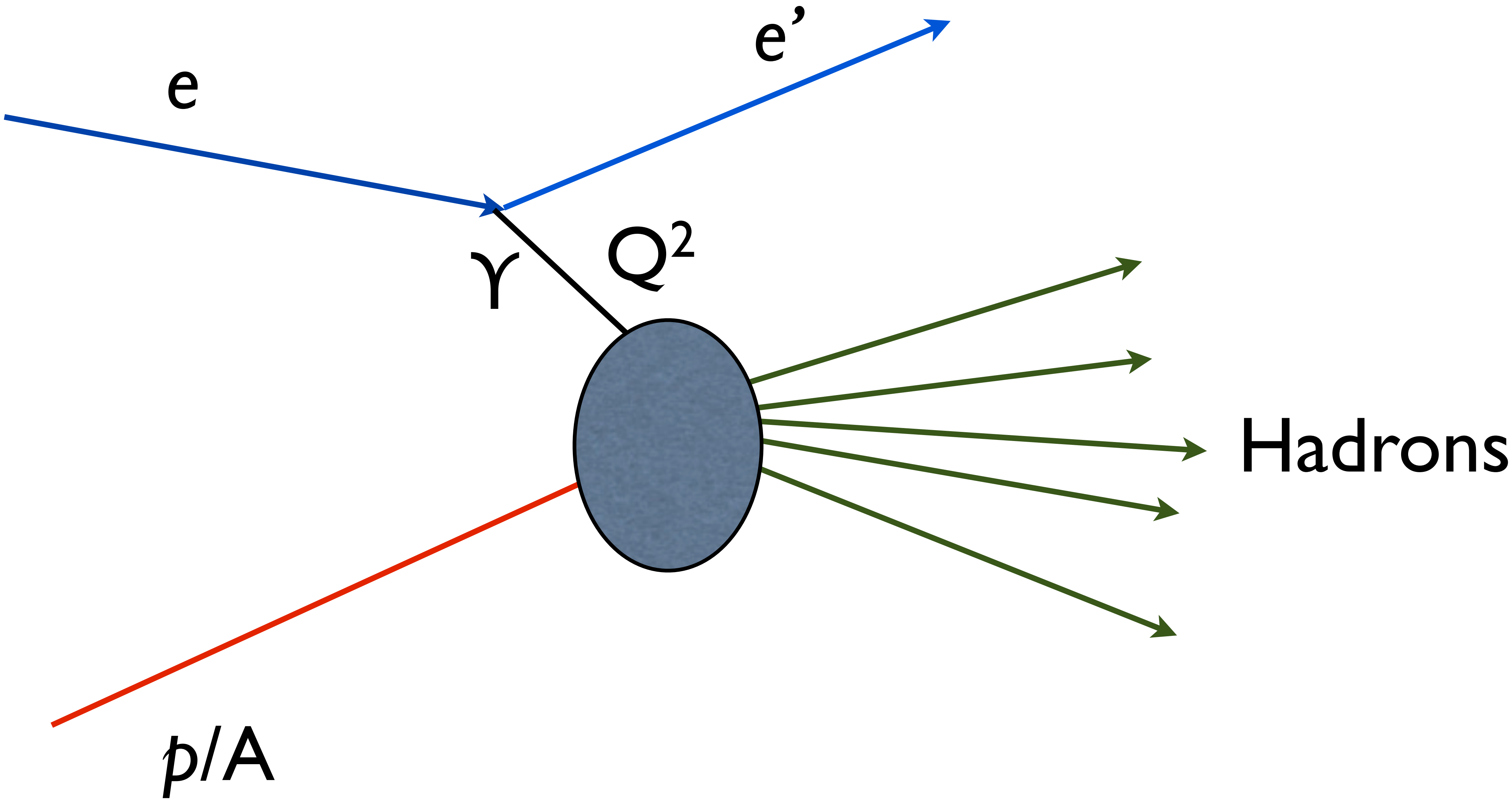


$$\langle q_\perp^2 \rangle_{dAu} = \langle q_\perp^2 \rangle_{pp} + \Delta \langle q_\perp^2 \rangle$$

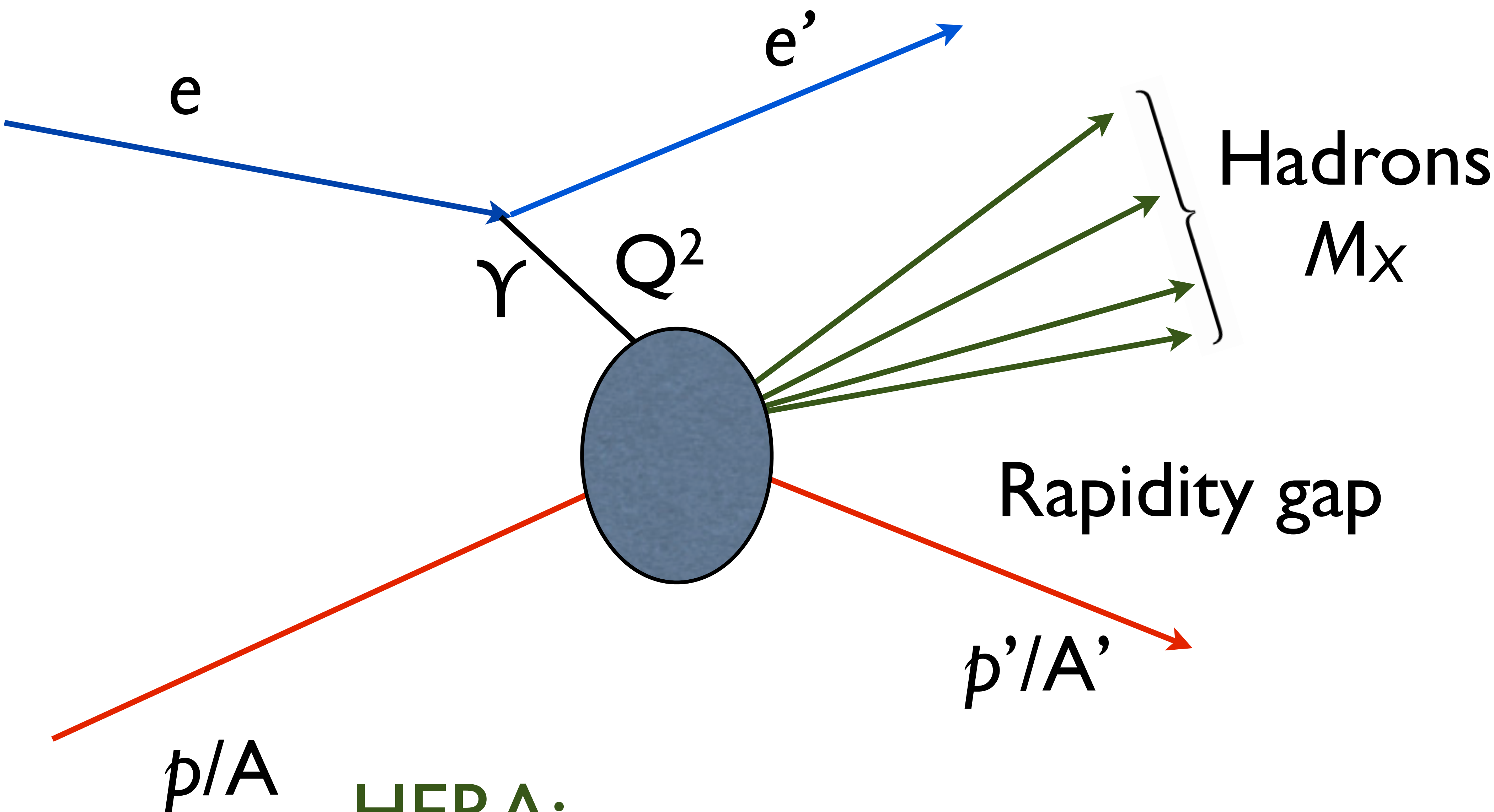
How saturated is the initial state?

What can eRHIC do?

DIS *ep* and eA



Diffraction *ep* and eA



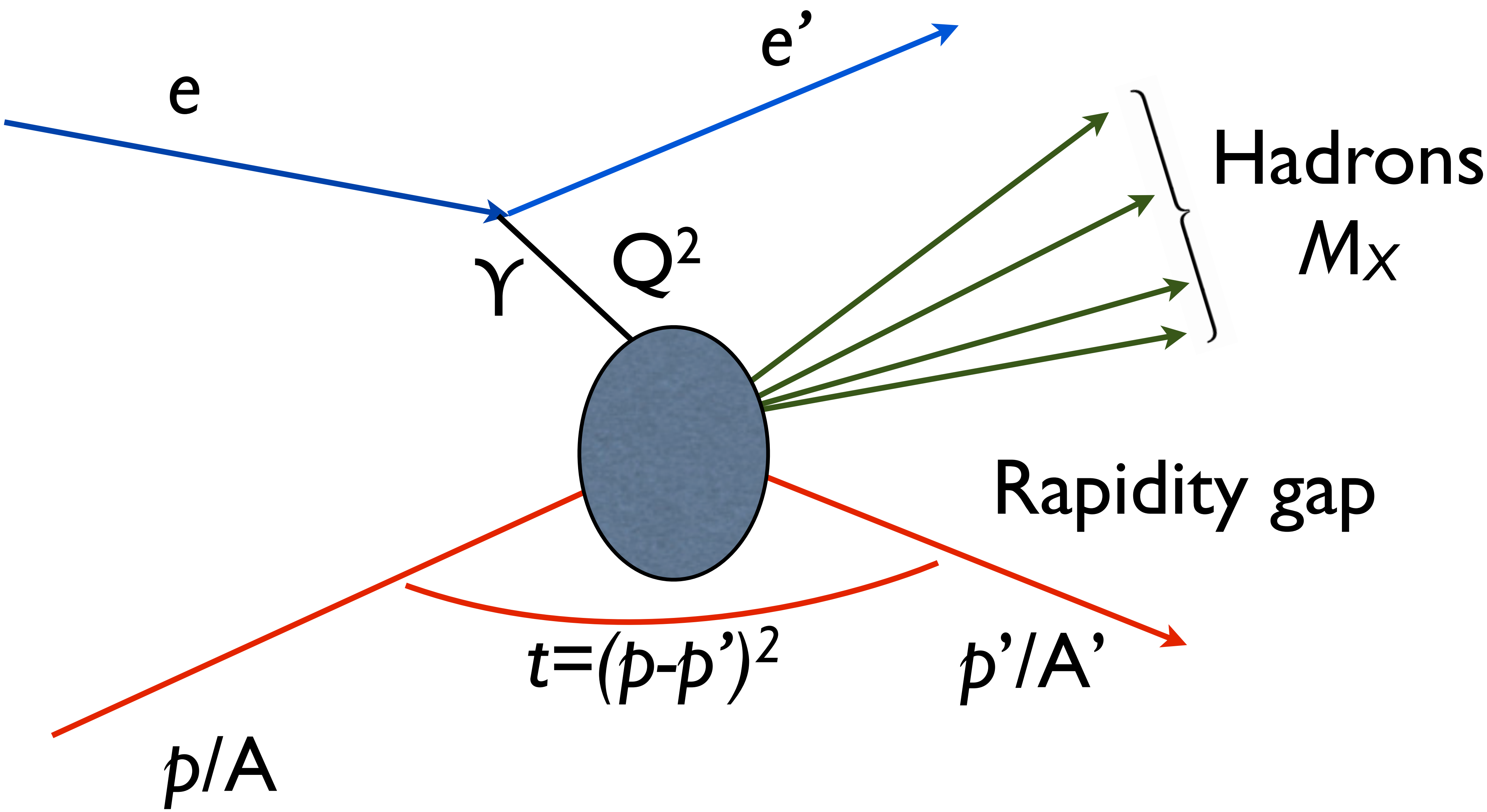
HERA:

Proton collides with electron at CMS energy ~300m_p.
In ~15% of measured collisions proton stays intact!

eRHIC e+A:

Ion predicted to stay intact in 25%-40% of events!

Diffraction *ep* and eA



Depend on *t*, momentum transfer to proton/ion.

Fourier transform of t-distribution

=

transverse spatial distribution

Spatial imaging!

Why is diffraction so great? Pt. I

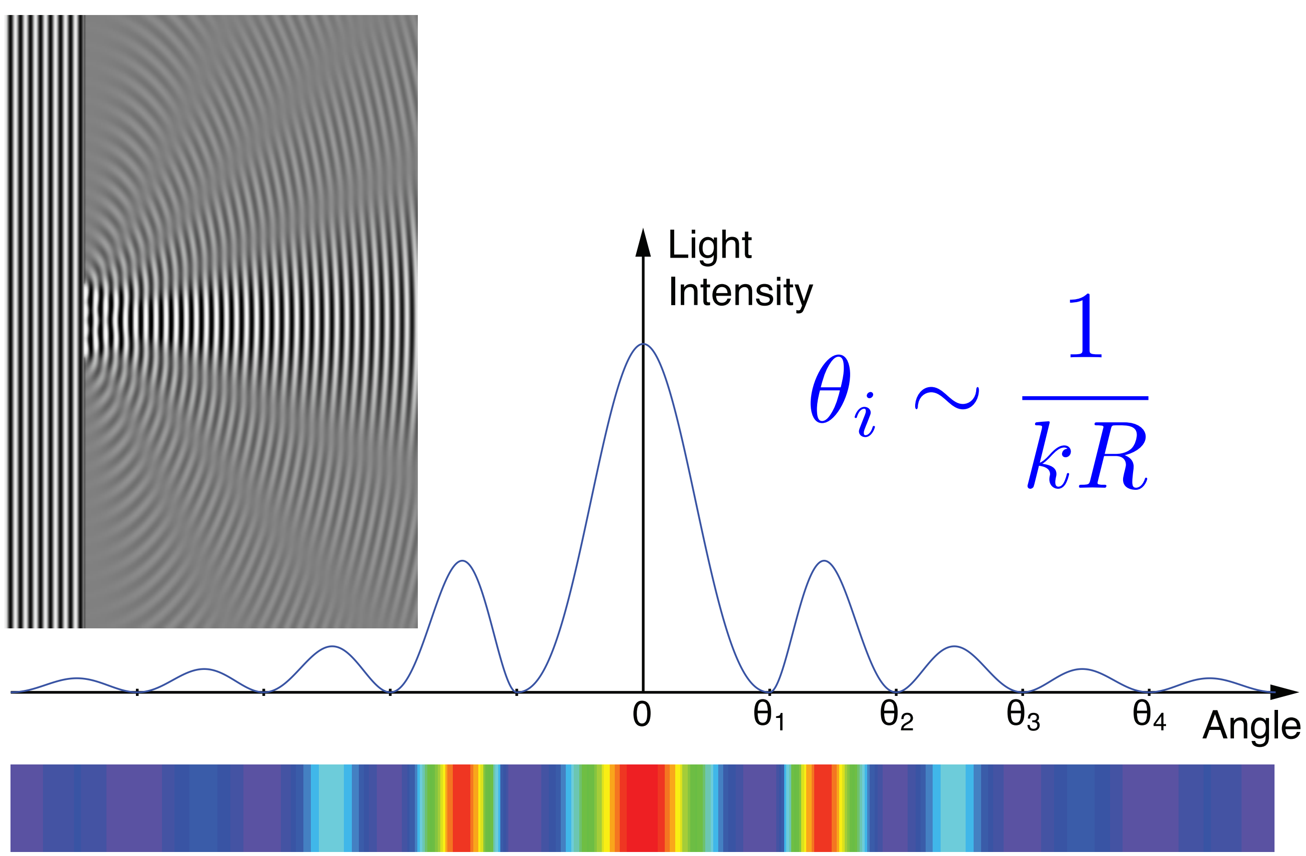
Sensitive to spatial gluon distributions

Light scattering off a circular screen of radius R

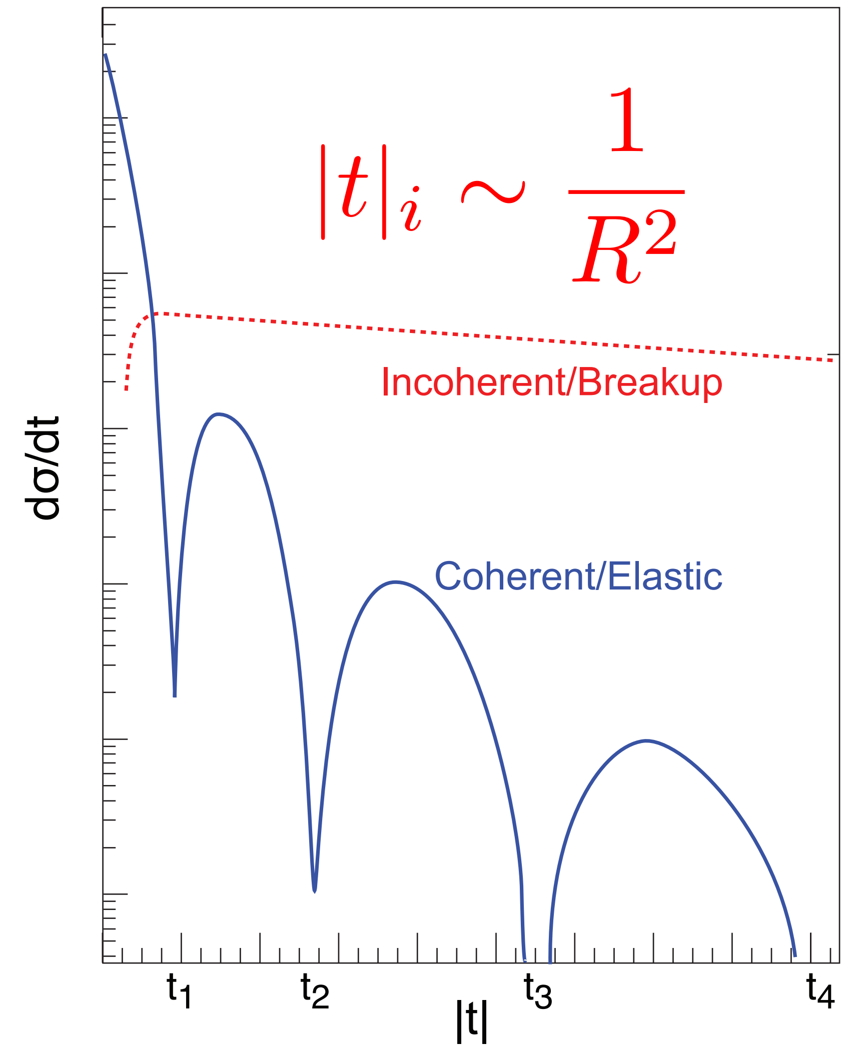
A projectile scattering off a nucleus of radius R

-not a 'black disk', edge effects

-target may break up



$$\theta_i \sim \frac{1}{kR}$$



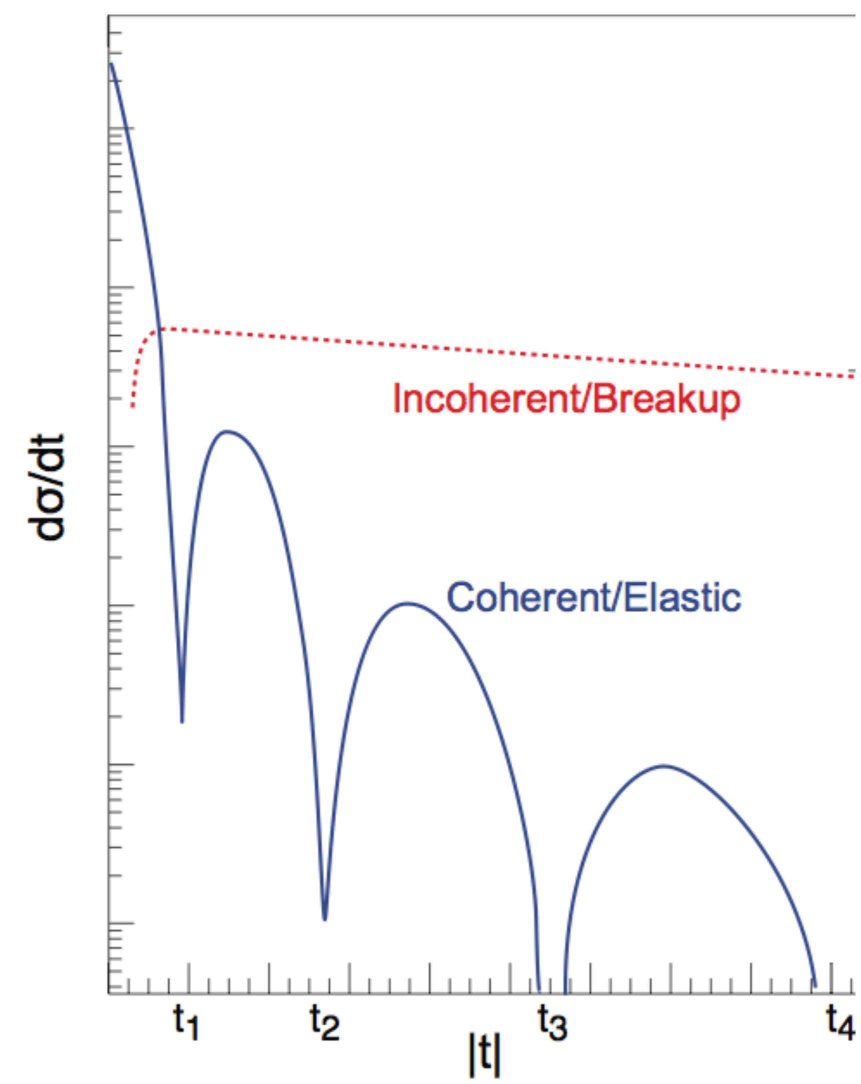
$$|t|_i \sim \frac{1}{R^2}$$

Diffraction at eRHIC

Difference in between *ep* & *eA*:
The nucleus can break up
into colour neutral fragments!

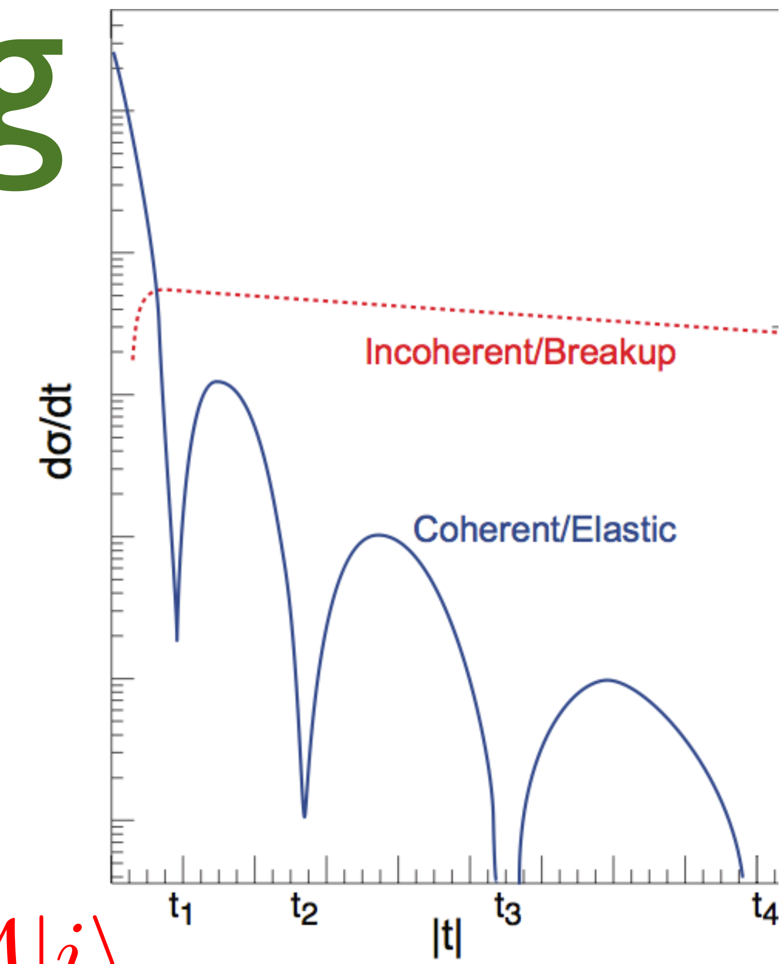
When the nucleus breaks up, the scattering is called incoherent

When the nucleus stays intact, the scattering is called coherent



Total cross-section = incoherent + coherent

Incoherent Scattering



Good, Walker:

Nucleus dissociates ($f \neq i$):

$$\sigma_{\text{incoherent}} \propto \sum_{f\neq i} \langle i|\mathcal{A}|f\rangle^\dagger \langle f|\mathcal{A}|i\rangle$$

complete set

$$= \sum_f \langle i|\mathcal{A}\underbrace{|f\rangle^\dagger \langle f|}\mathcal{A}|i\rangle - \langle i|\mathcal{A}|i\rangle^\dagger \langle i|\mathcal{A}|i\rangle$$

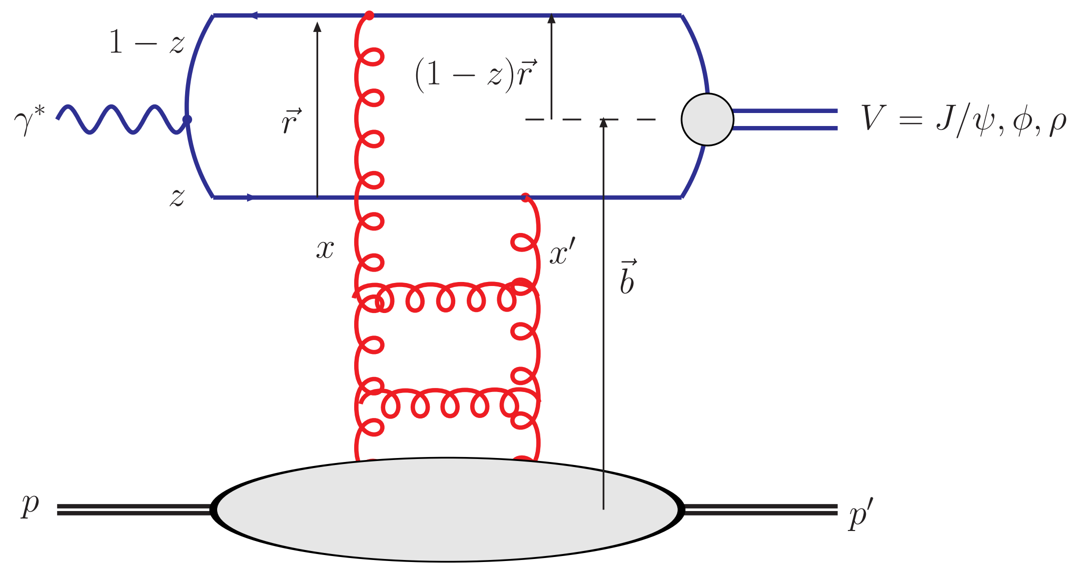
$$= \left\langle i \left| |\mathcal{A}|^2 \right| i \right\rangle - \left|\langle i|\mathcal{A}|i\rangle\right|^2 = \left\langle |\mathcal{A}|^2 \right\rangle - \left|\langle \mathcal{A}\rangle\right|^2$$

The incoherent CS is the variance of the amplitude!!

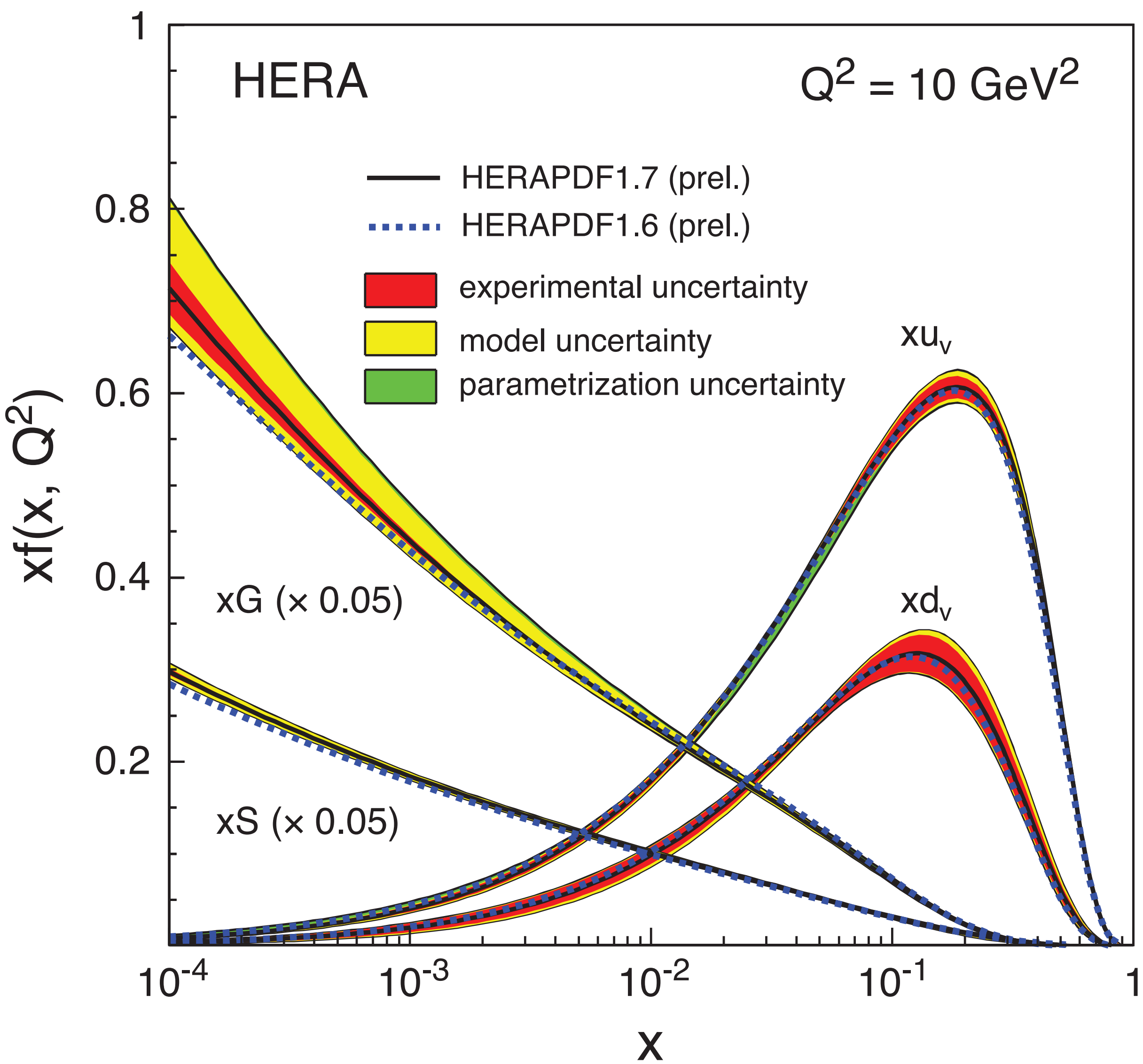
$$\frac{d\sigma_{\text{total}}}{dt} = \frac{1}{16\pi}\left\langle |\mathcal{A}|^2 \right\rangle \qquad \frac{d\sigma_{\text{coherent}}}{dt} = \frac{1}{16\pi}\left|\langle \mathcal{A}\rangle\right|^2$$

Why is diffraction so great? Pt. 2

Diffraction sensitive to gluon momentum distributions[2]:

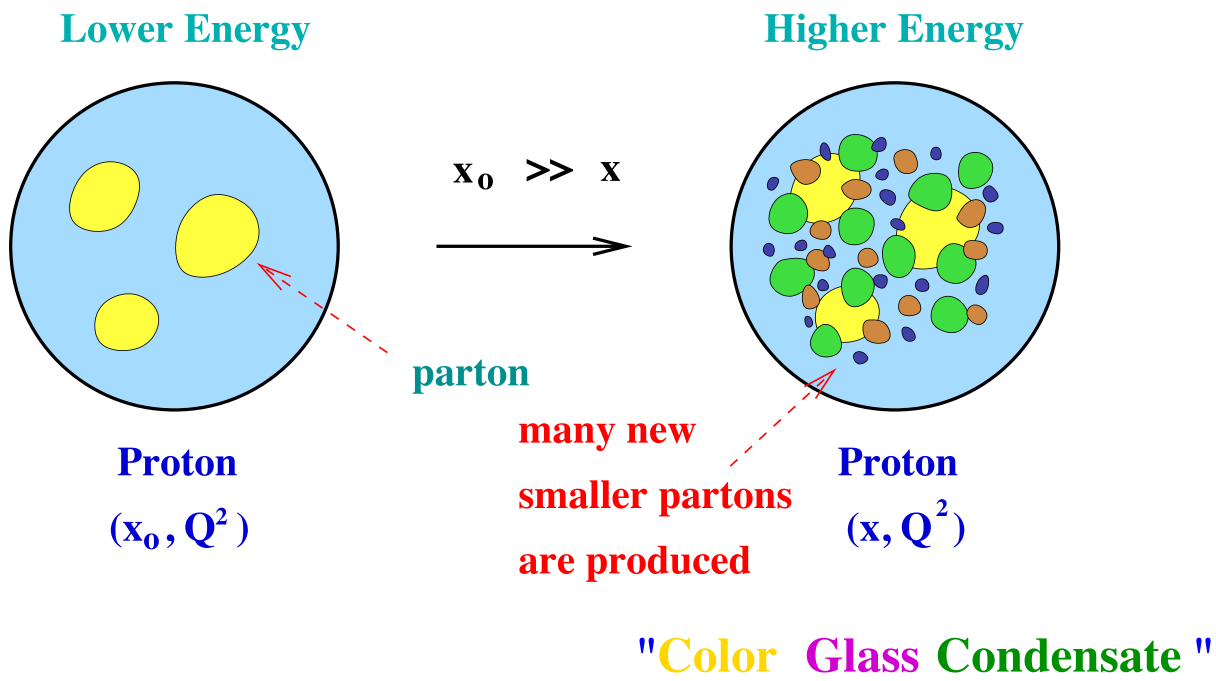


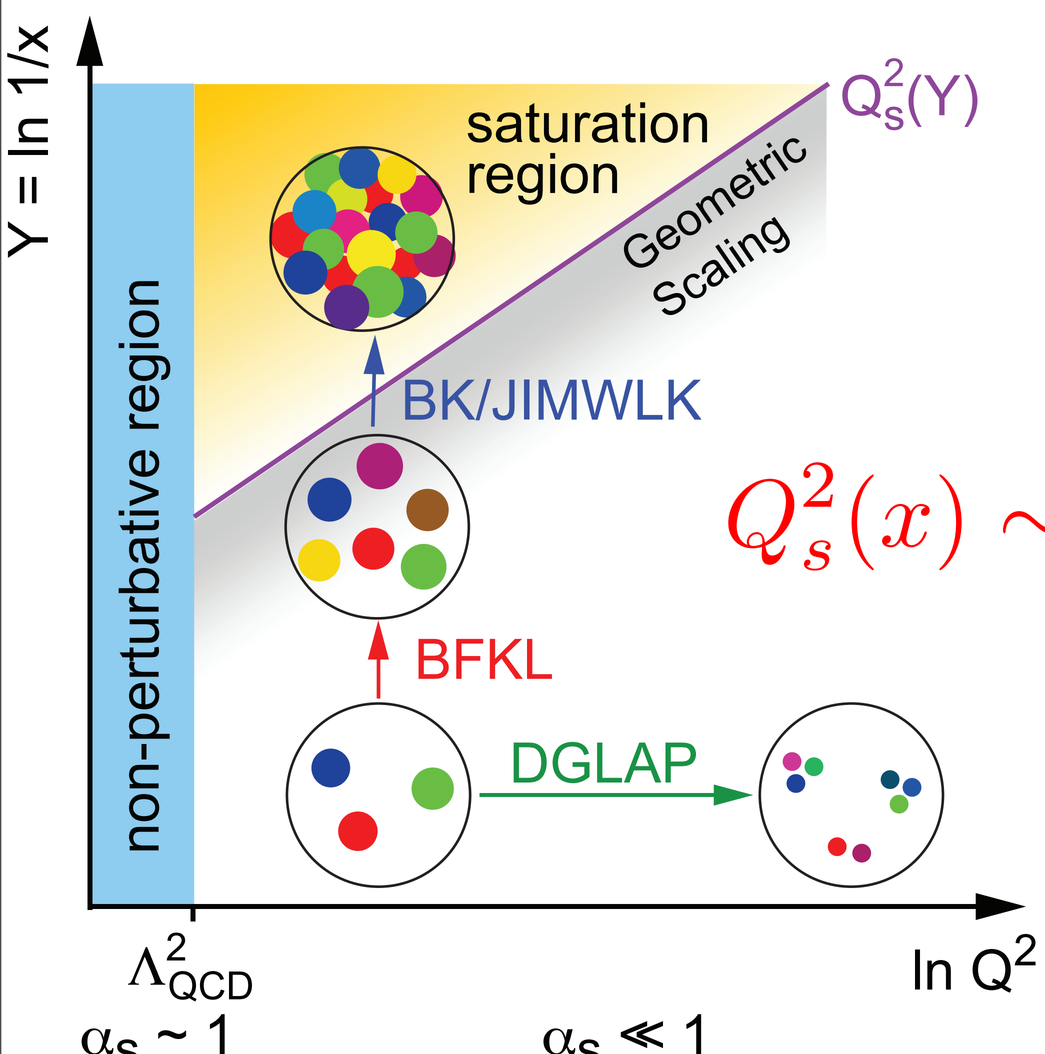
$$\sigma \propto g(x,Q^2)^2$$



How does the gluon distribution saturate at small *x*?

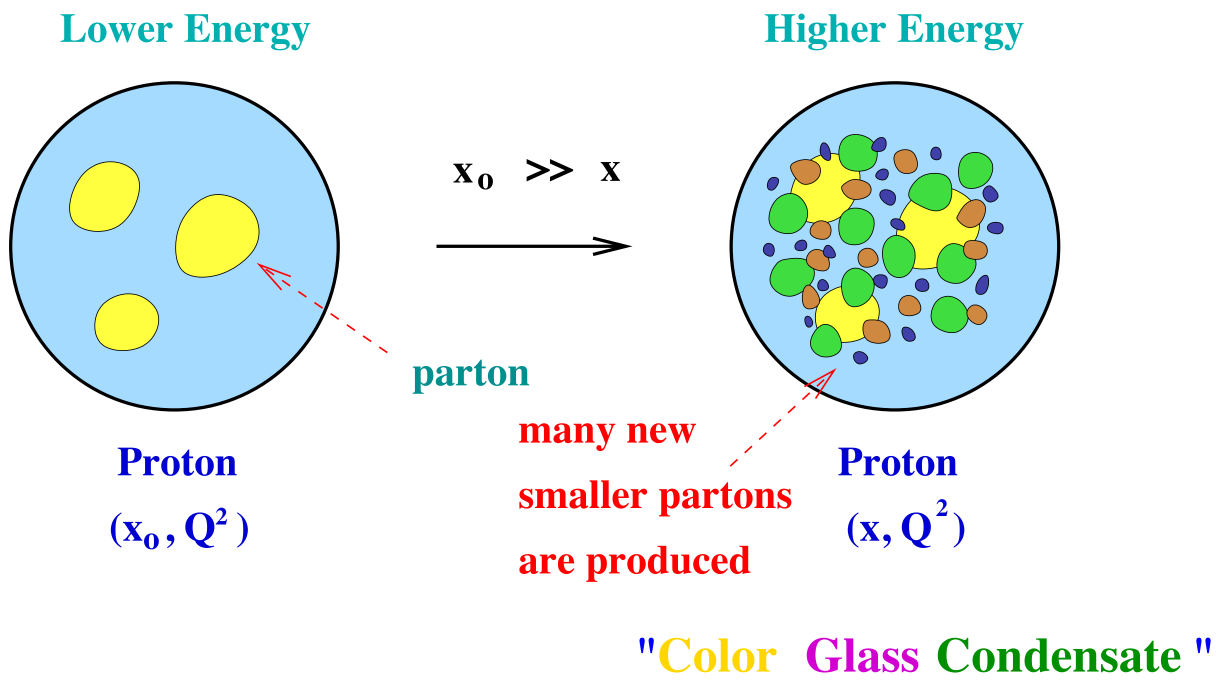
Saturation at eRHIC

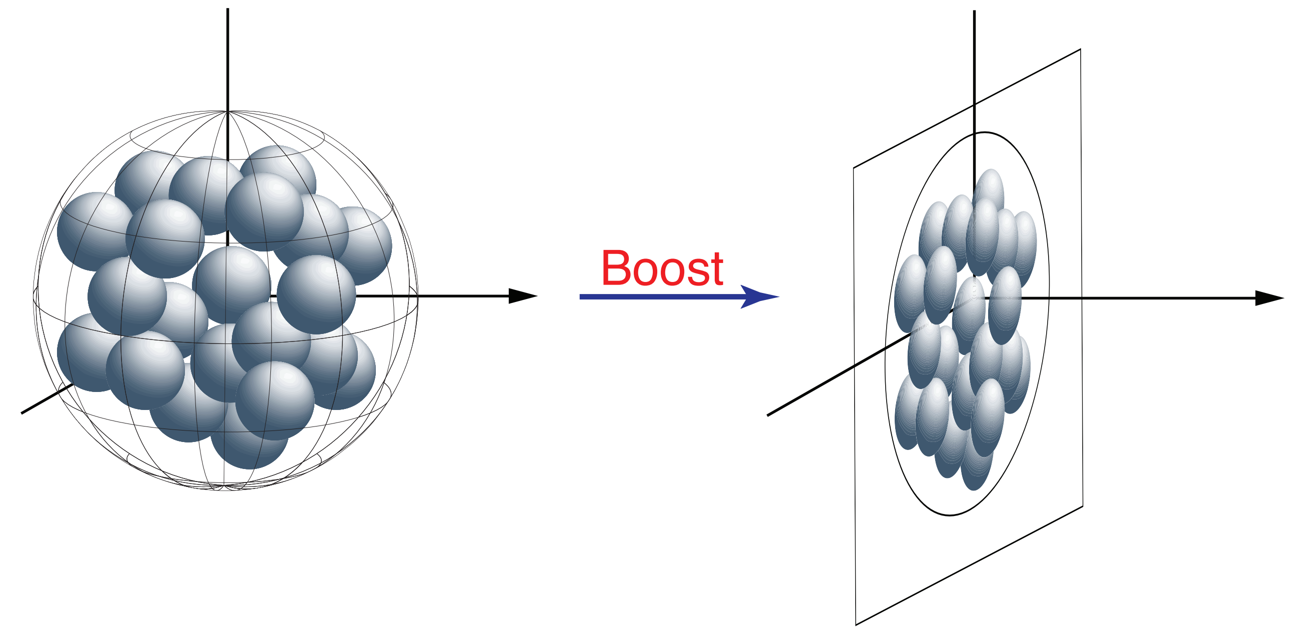


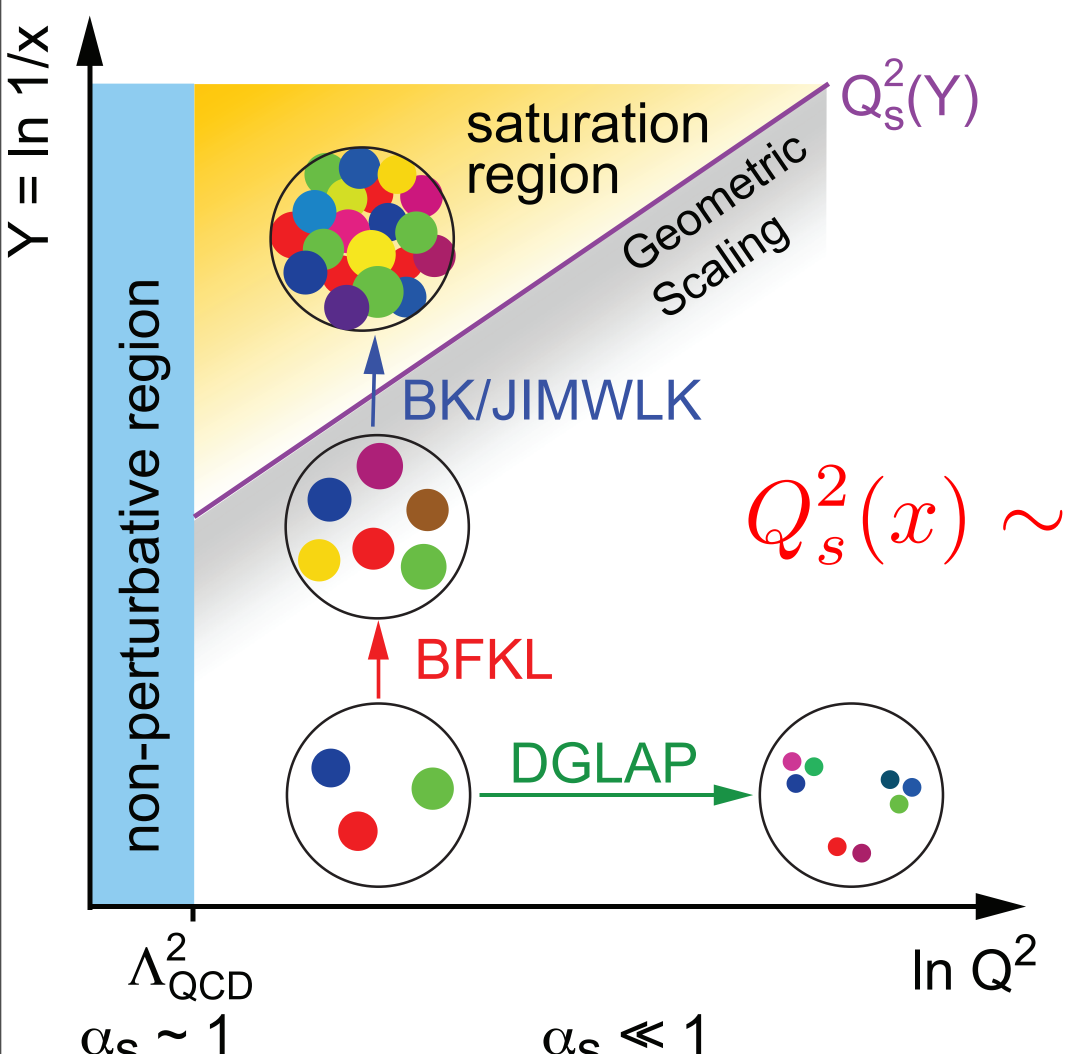


$$Q_s^2(x) \sim \left(\frac{1}{x}\right)^{\lambda}$$

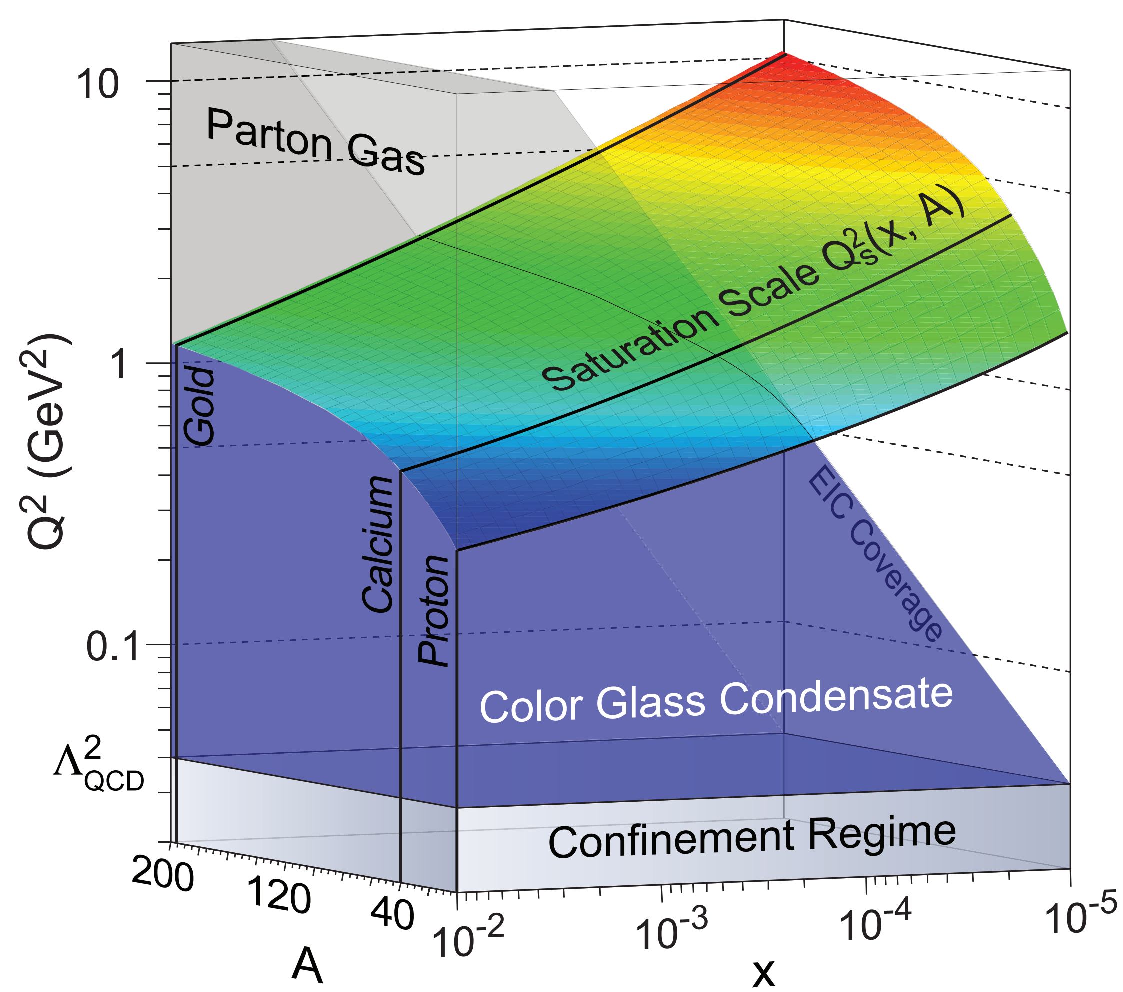
Saturation at eRHIC







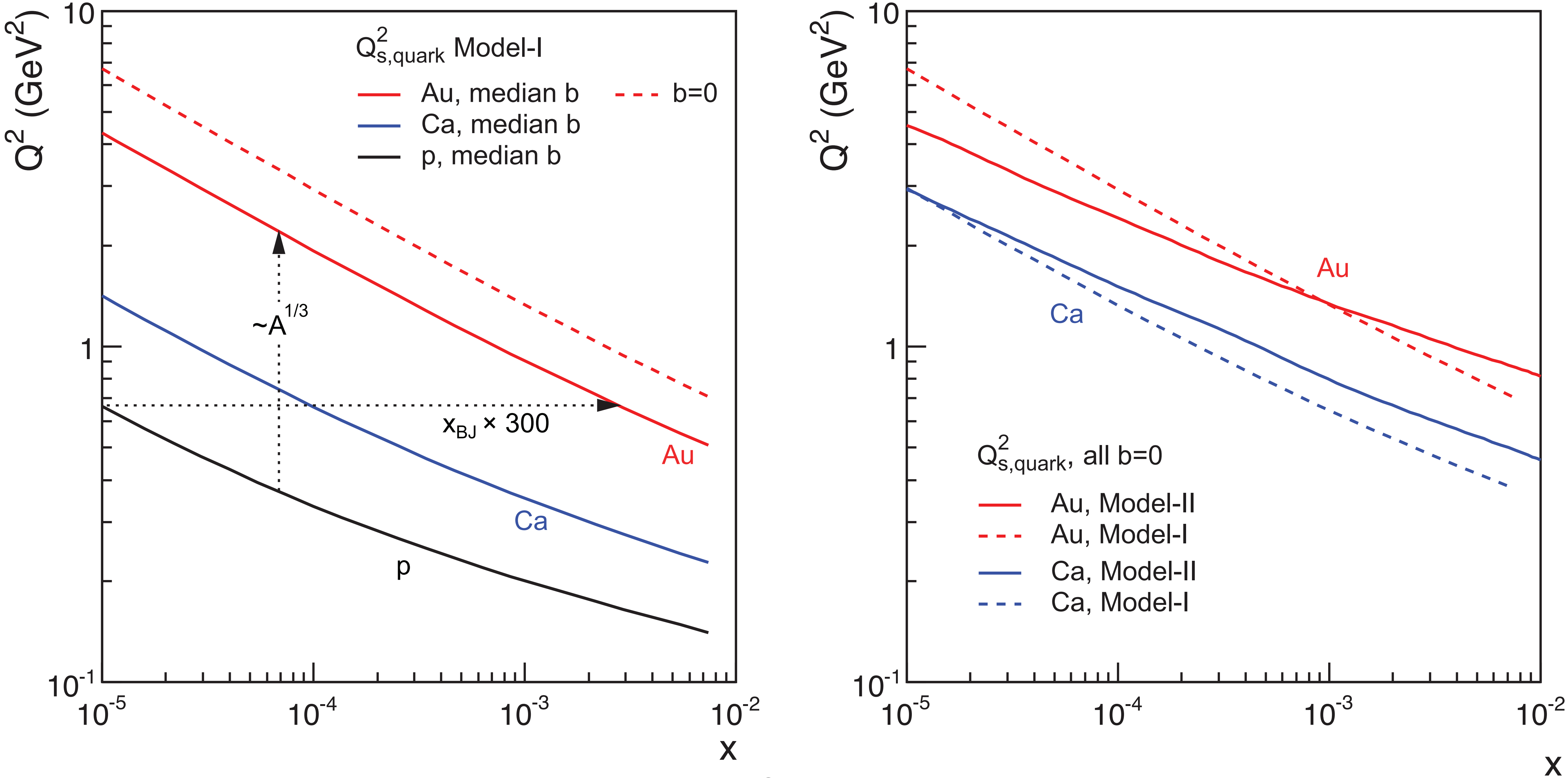
$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x}\right)^{\lambda}$$



Saturation at eRHIC

Pocket formula: $Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$

Gold: A=197, *x* 197 times smaller!



Model-I: bSat, Model-II: rcBK

Saturation at eRHIC

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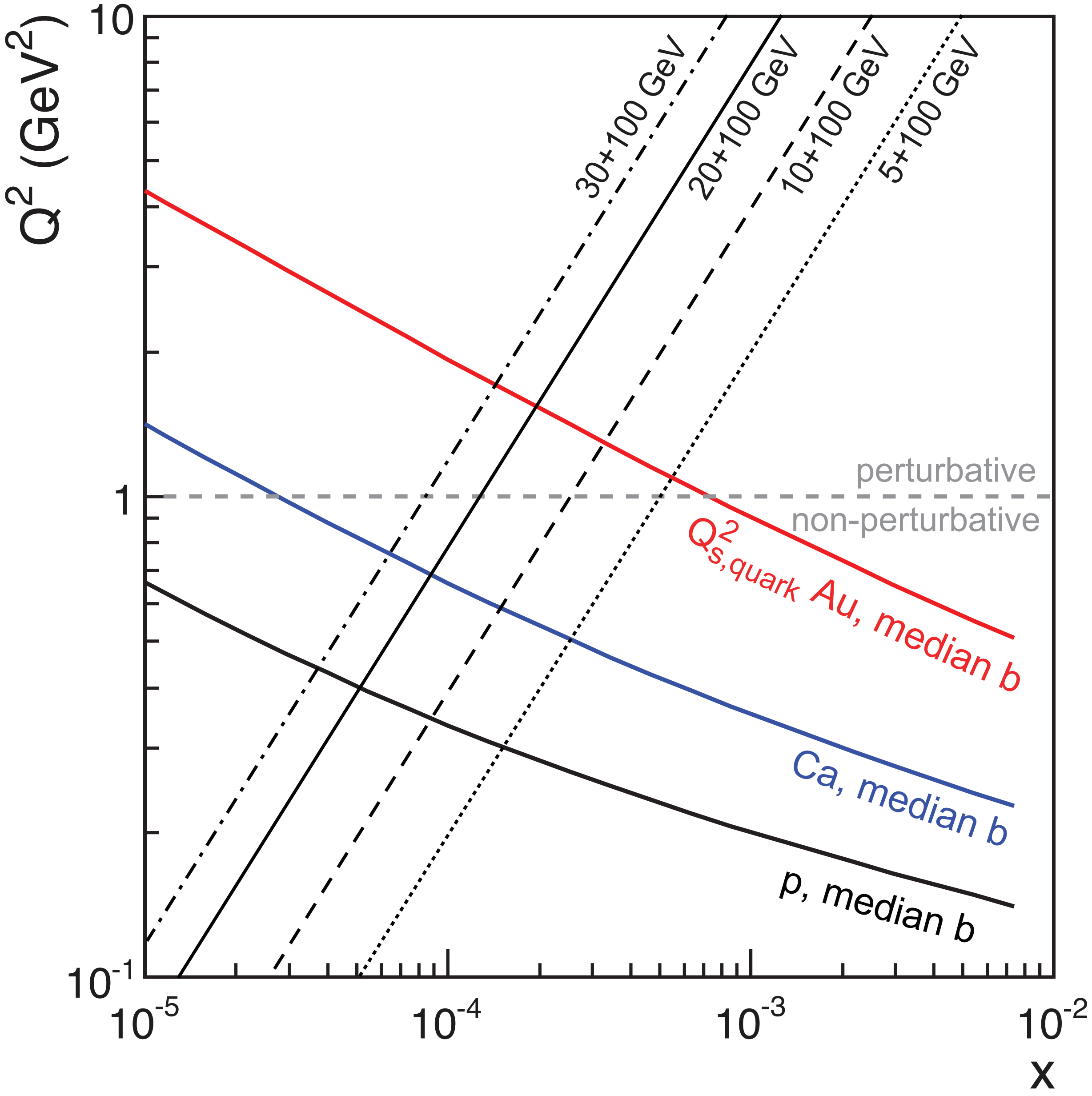
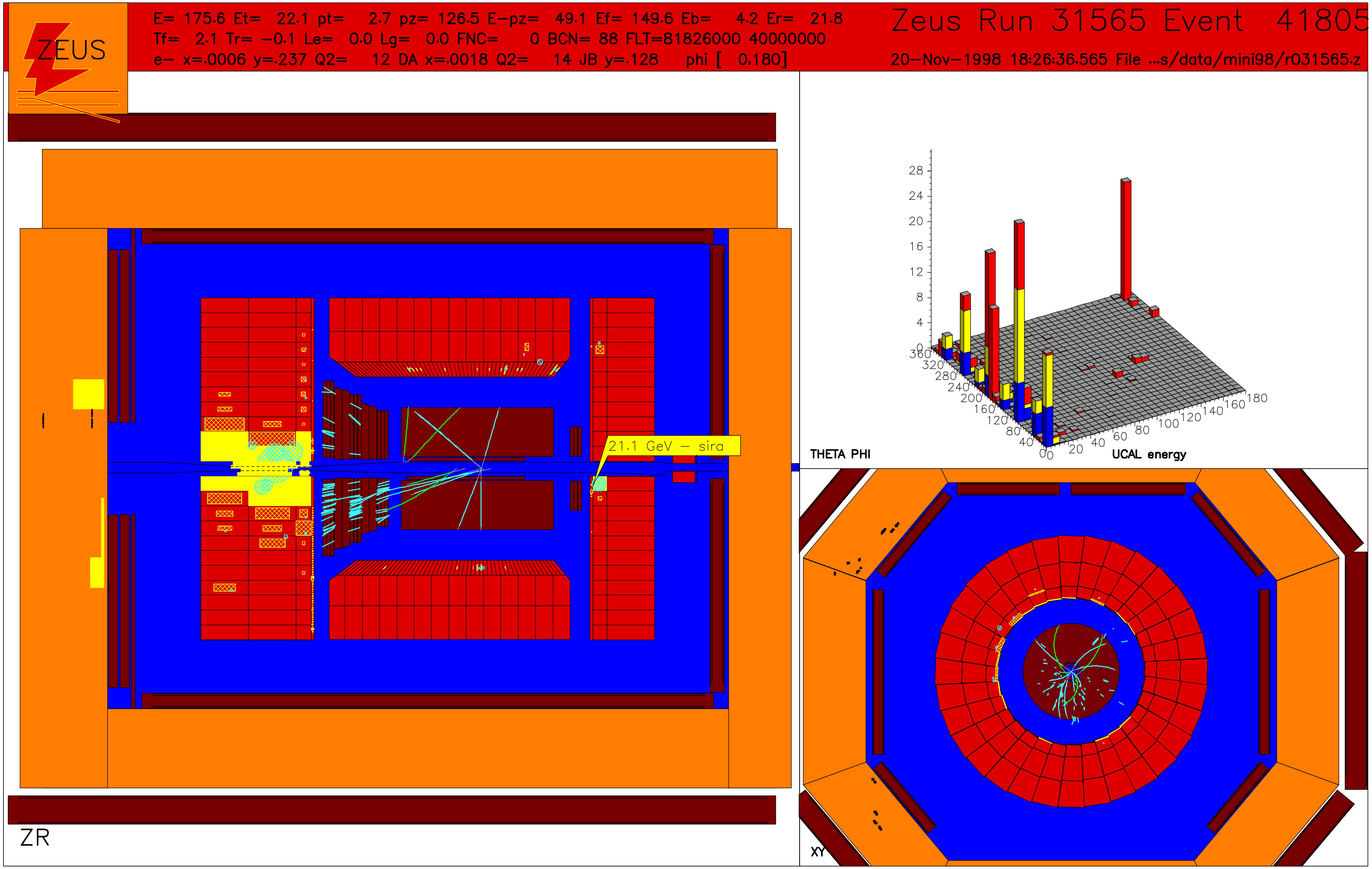


How to measure diffraction at eRHIC

“Seeing” Diffraction

Slides from T. Ullrich

A DIS event (experimental view)



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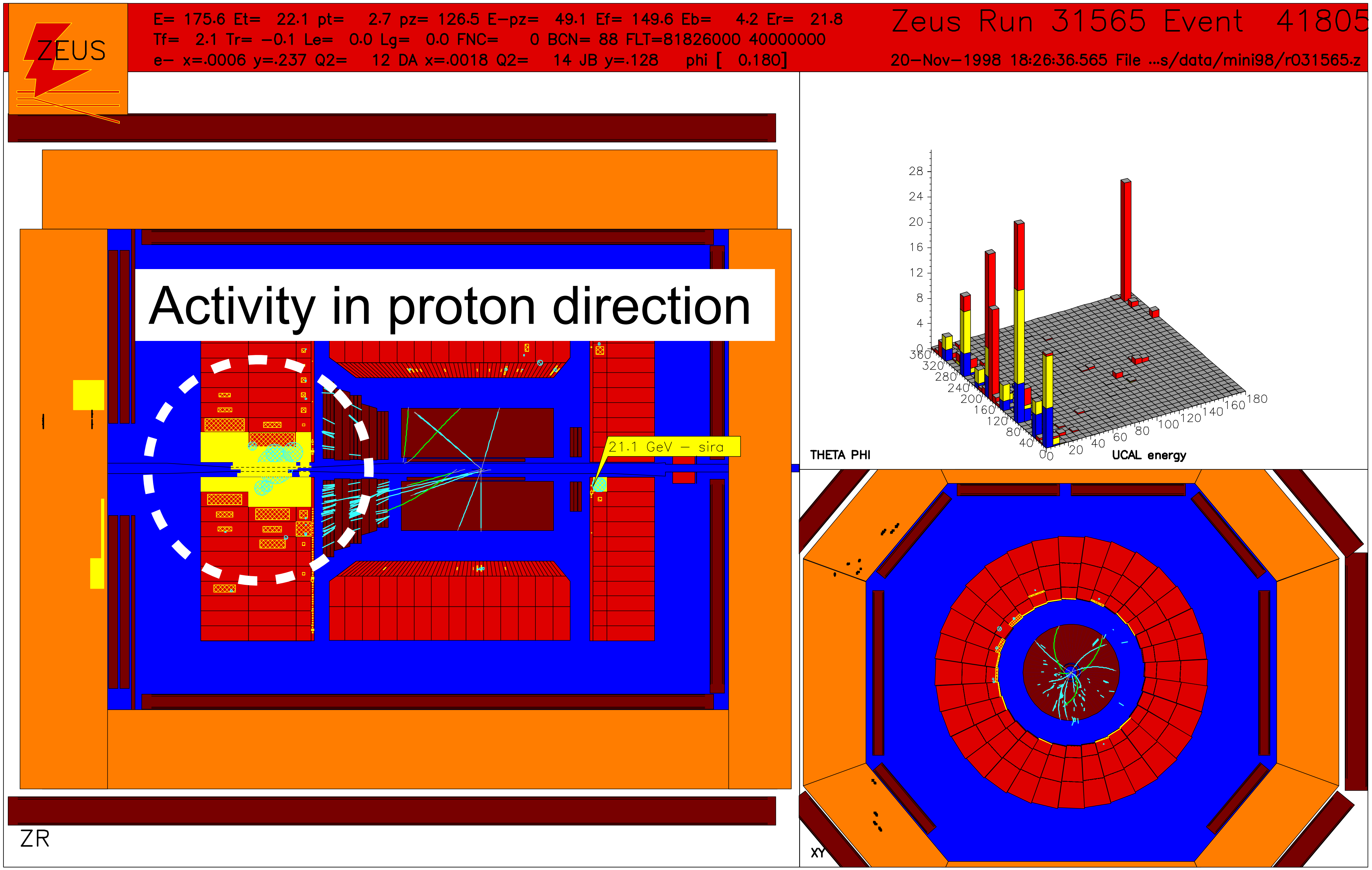

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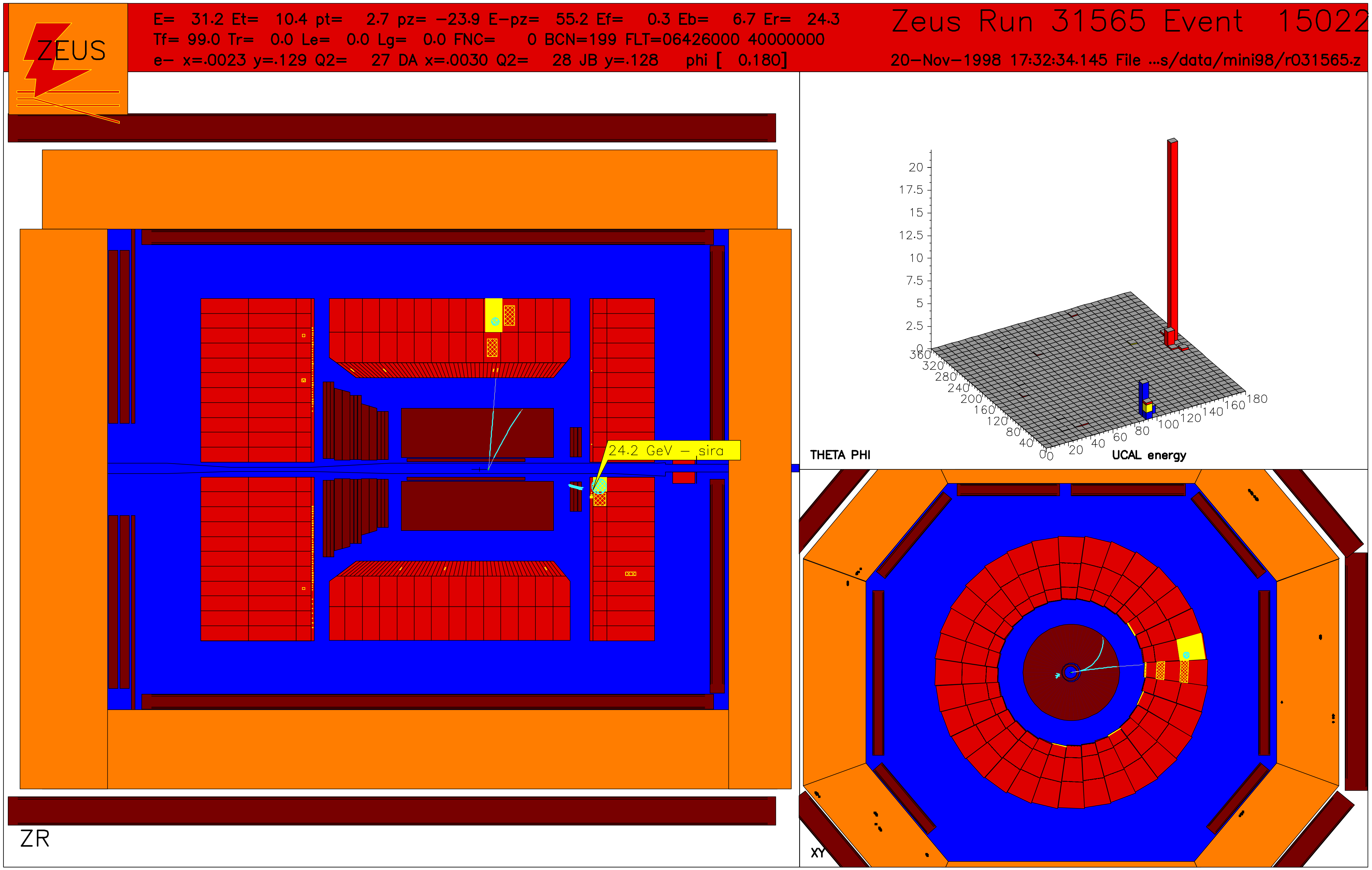

“Seeing” Diffraction

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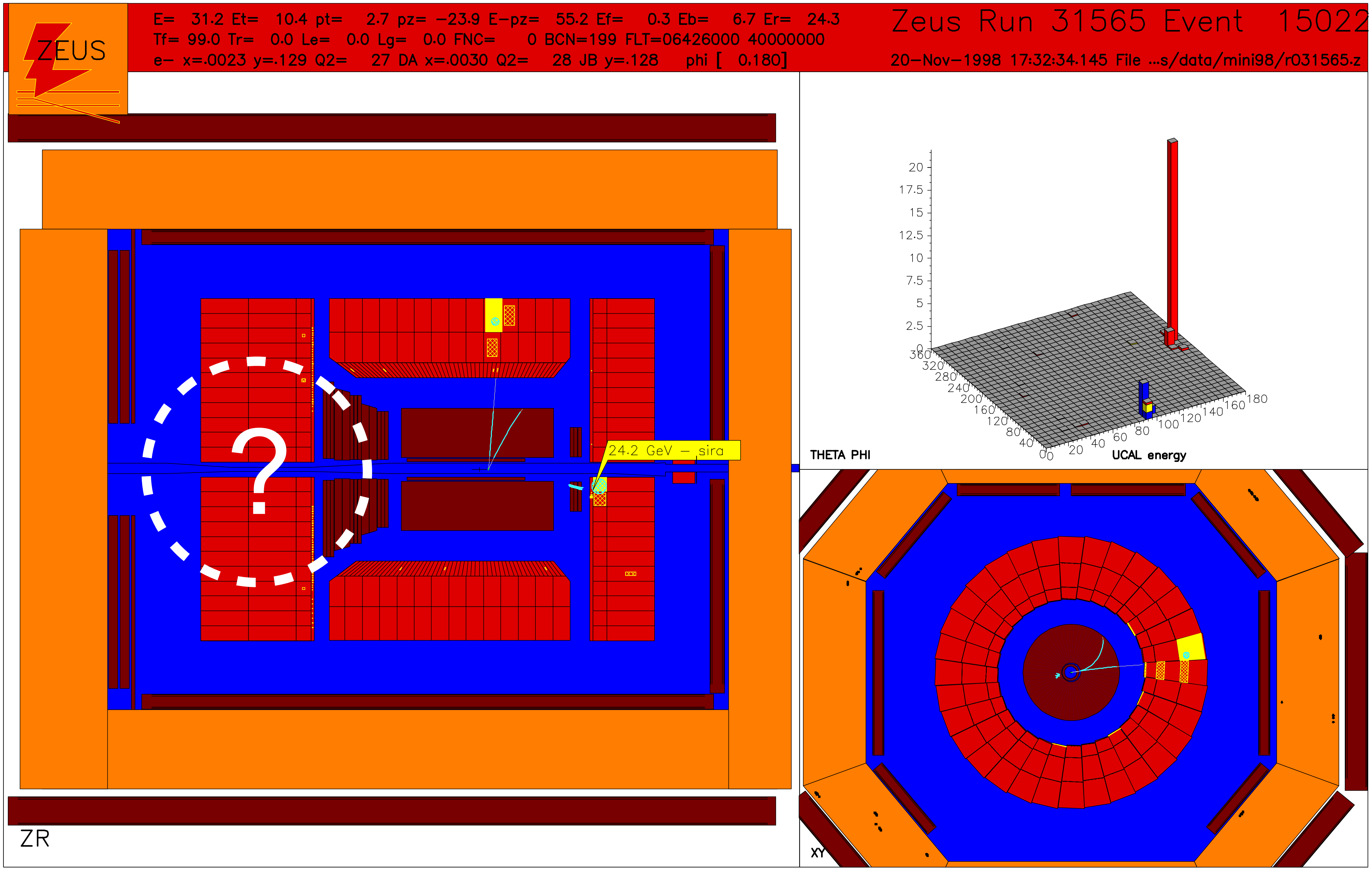
A diffractive event (experimental view)



How to measure $t=(P_A-P_{A'})^2$

Need to measure $P_{A'}$

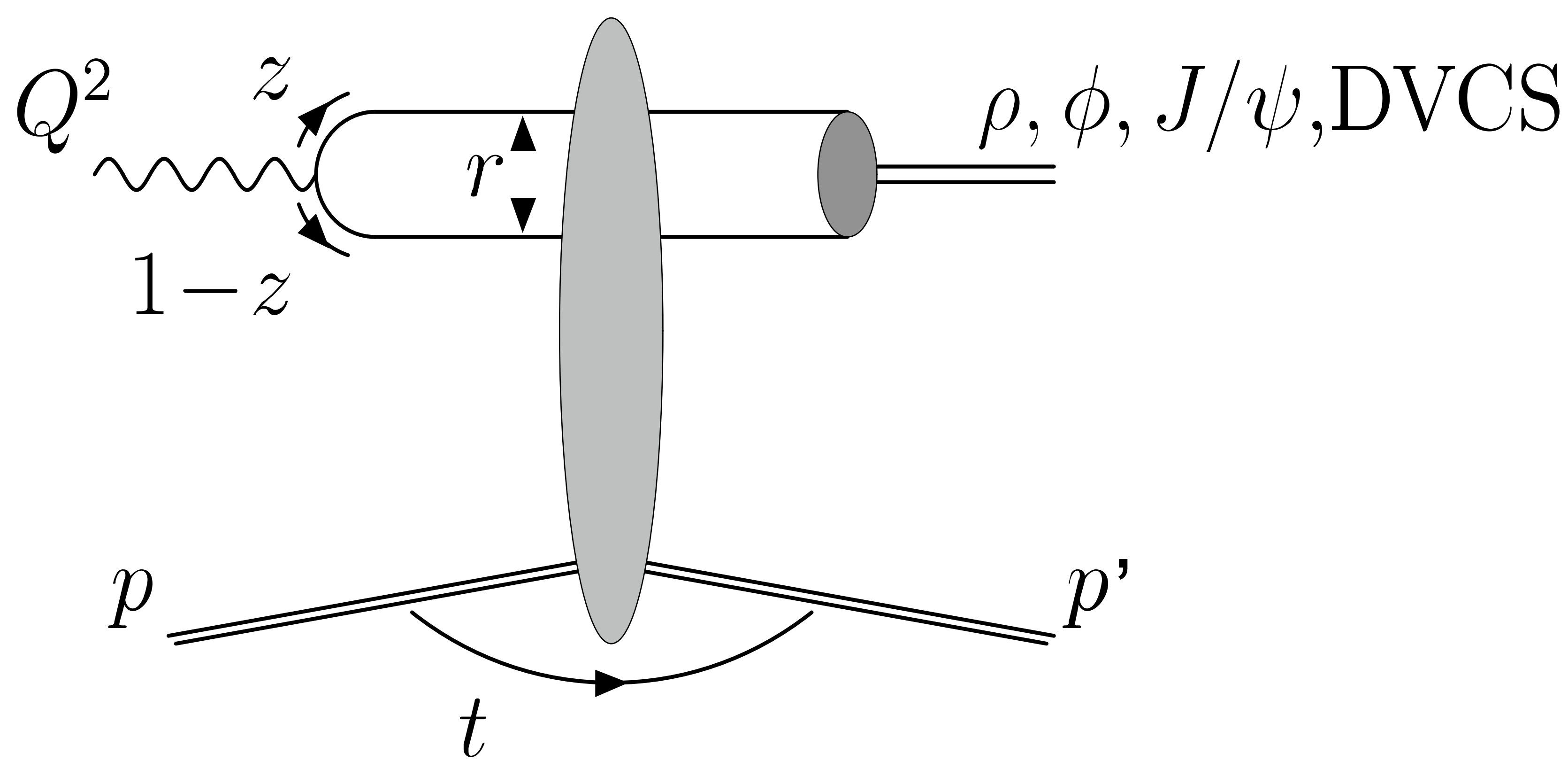
Coherent case: A' disappears down beampipe

Incoherent case: Cannot measure all beam remnants

Only possibility: Exclusive diffraction

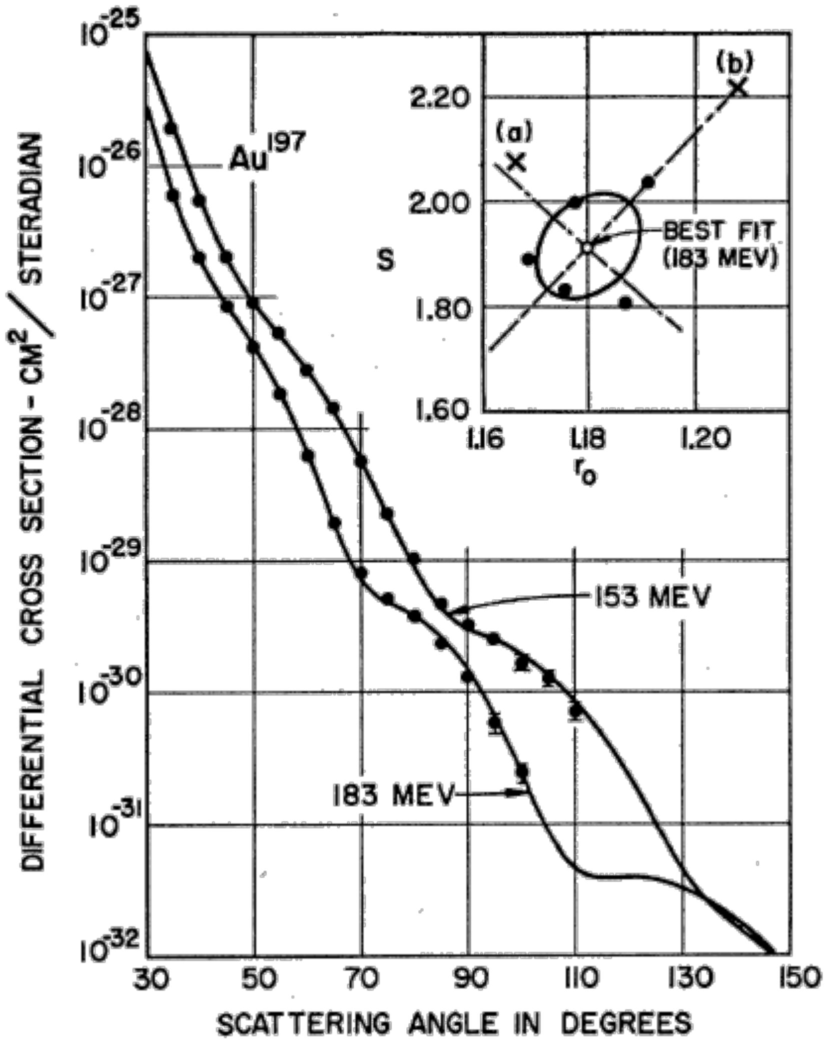
$e+A \rightarrow e'+VM+A'$

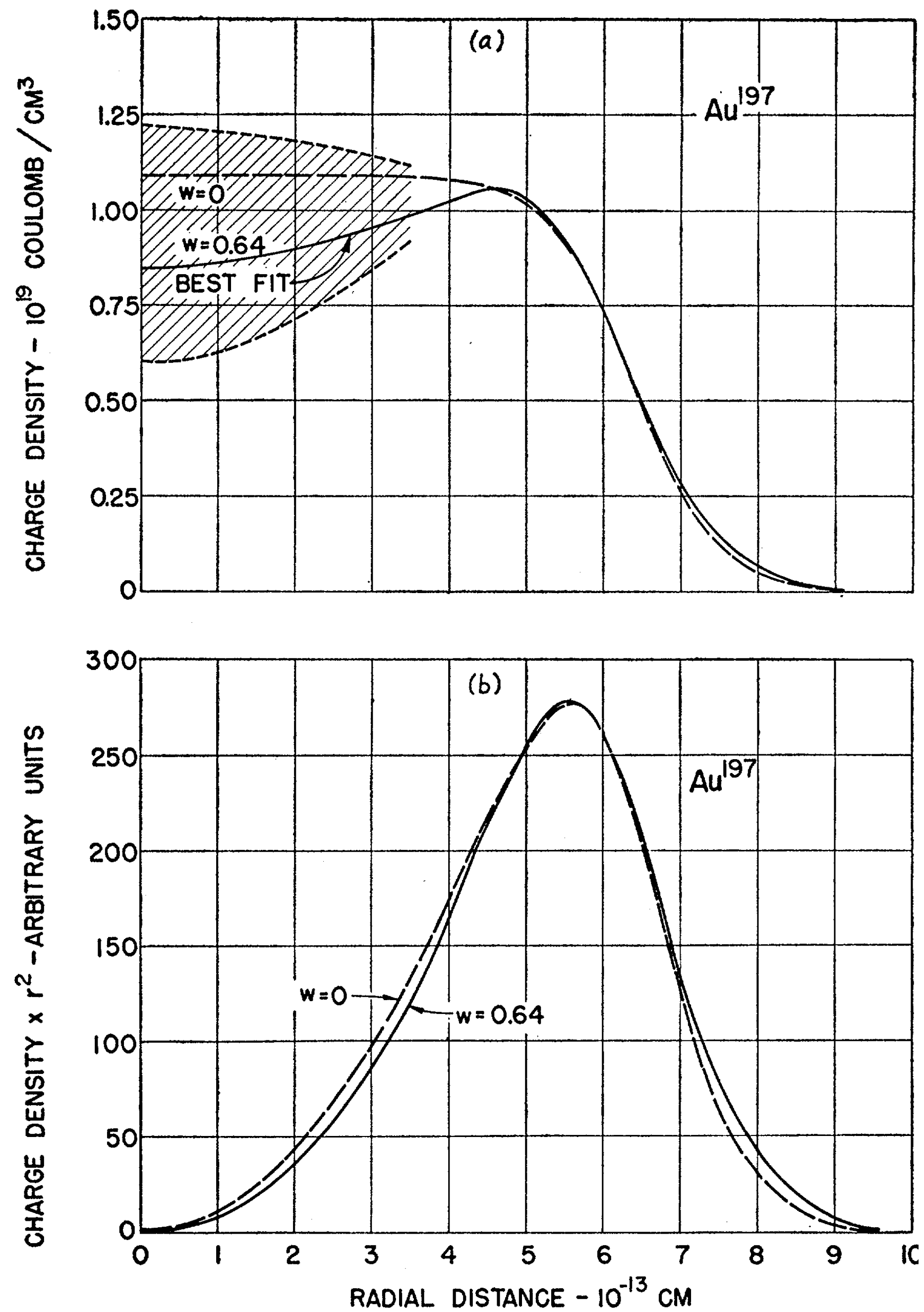
$t=(P_{VM}+P_{e'}-P_e)^2$



What has been measured?

Hahn, Ravenhall, and Hofstadter,
Phys Rev 101 (1956)



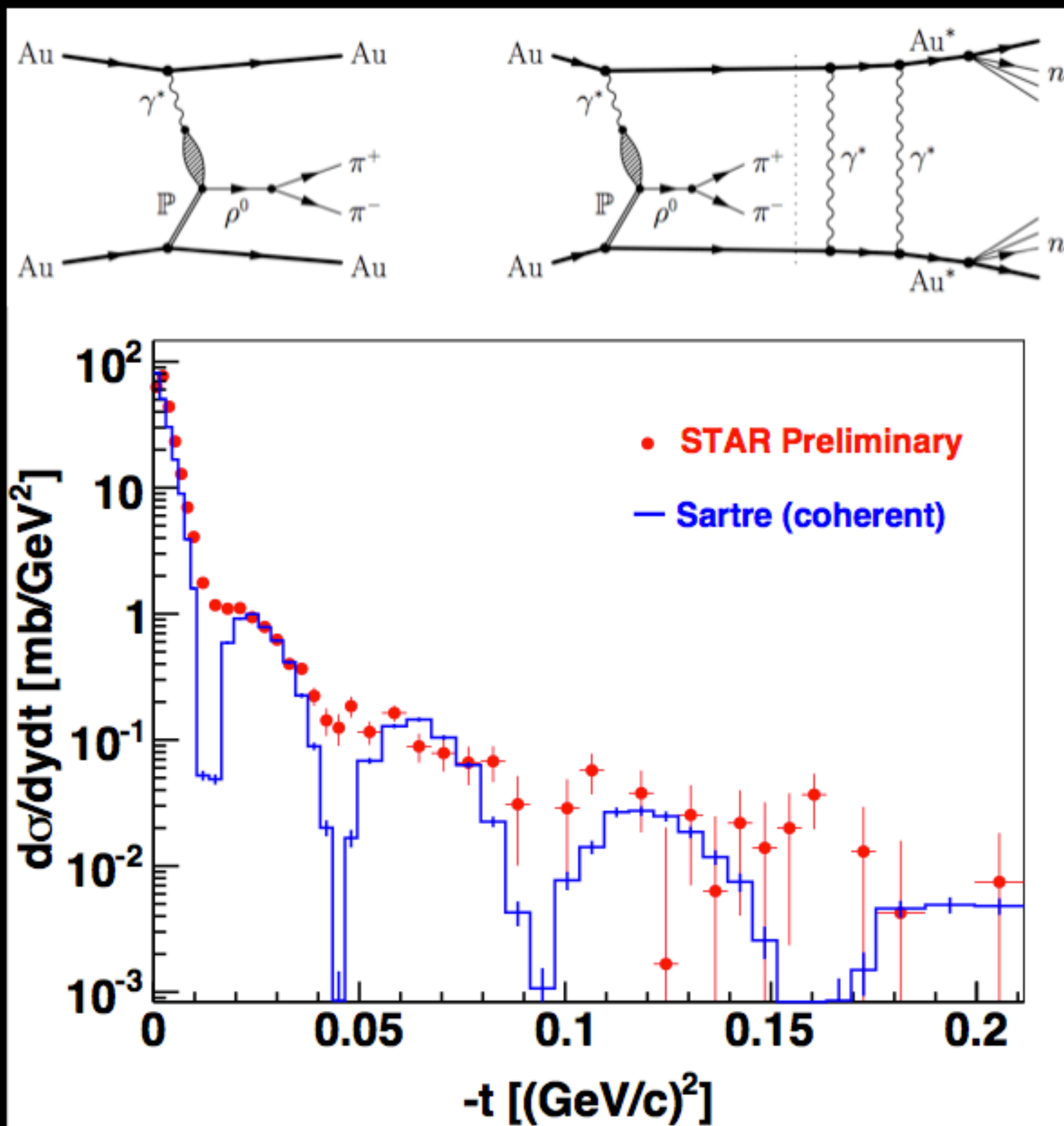


Electron colliding with fixed ion target, large *x* charge distribution - no gluons!

What is being measured?

Coherent Diffraction (γ*+IP) in UPC at RHIC

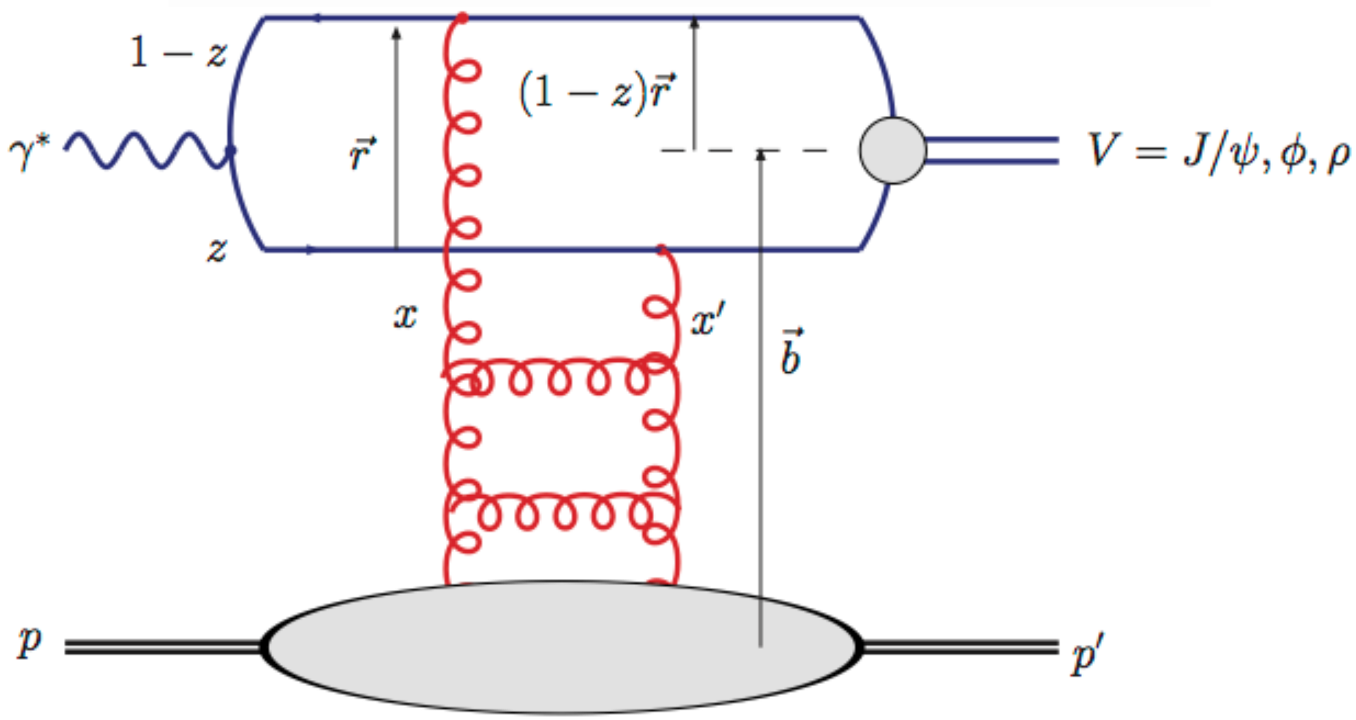
Slide from J.H. Lee, Analysis: R. Debbe

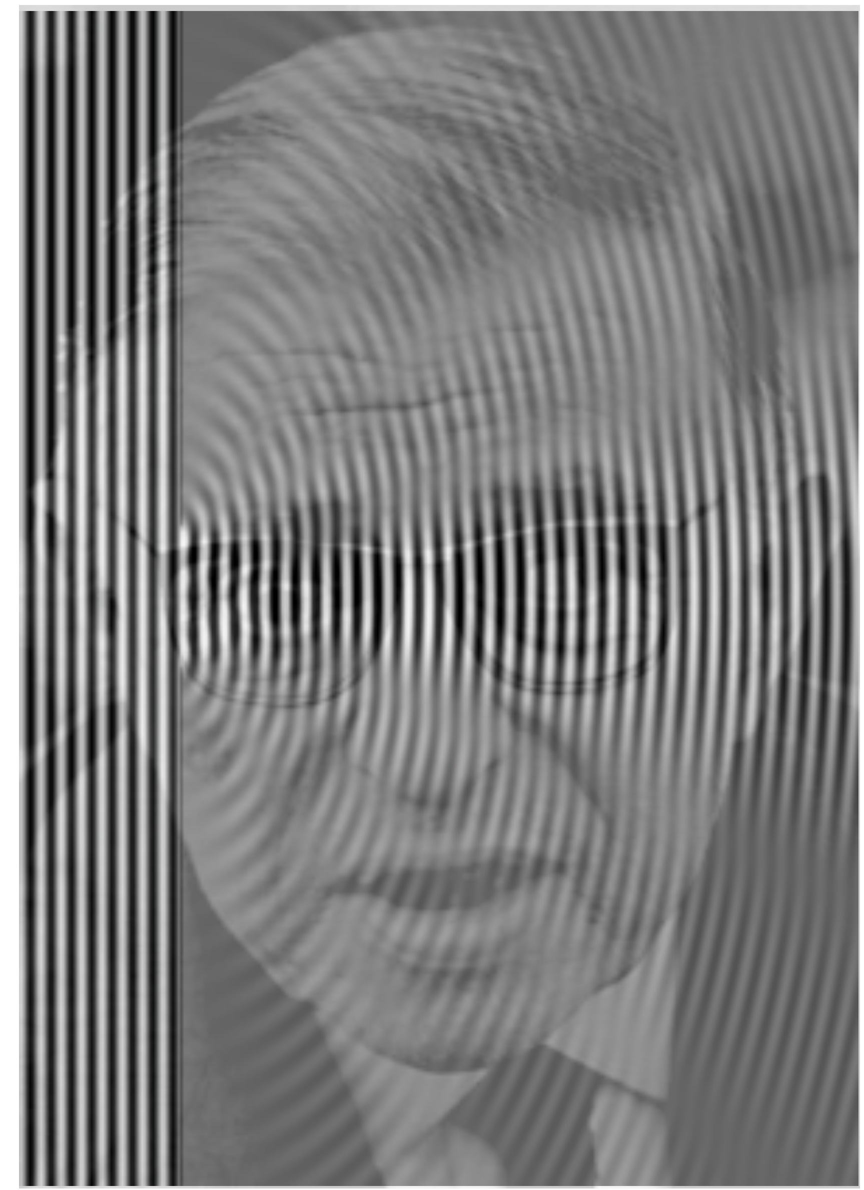


- Coherent diffractive ρ production in Au+Au at $\sqrt{s_{NN}}$=200 GeV
- Data: STAR/RHIC Ultra-peripheral AuAu Collision
- Simulation: Sartre

No t-smearing in Sartre

eRHIC predictions: Exclusive diffraction Sartre





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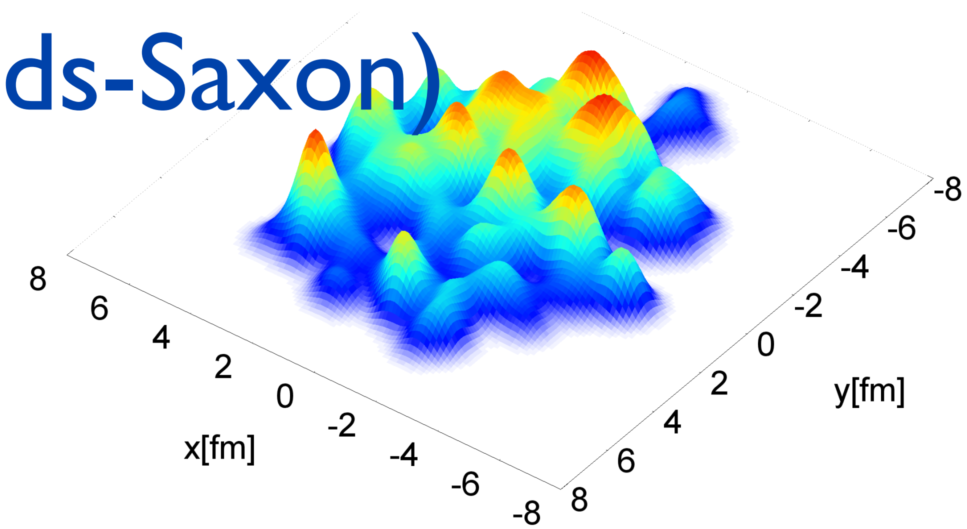
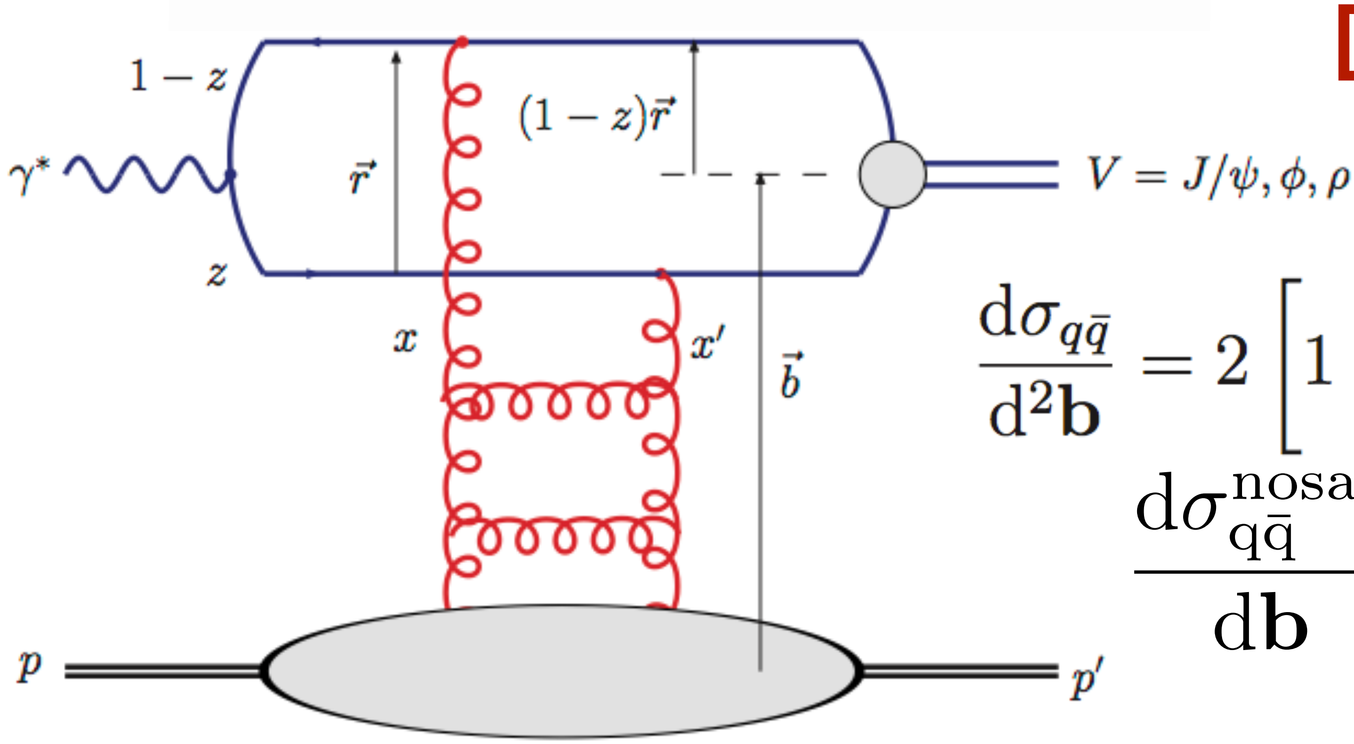


T. Ullrich & T.T.

eRHIC predictions: Exclusive diffraction Sartre



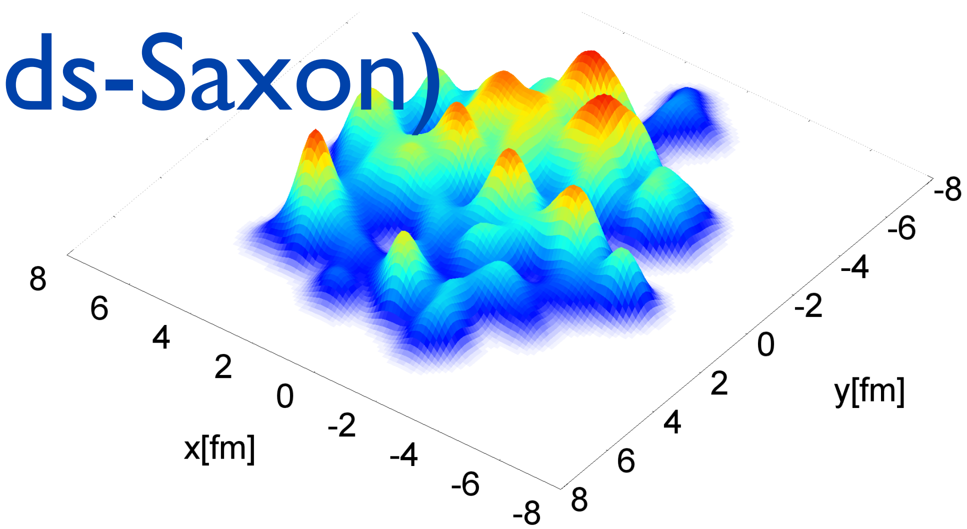
Dipole model with Glauber

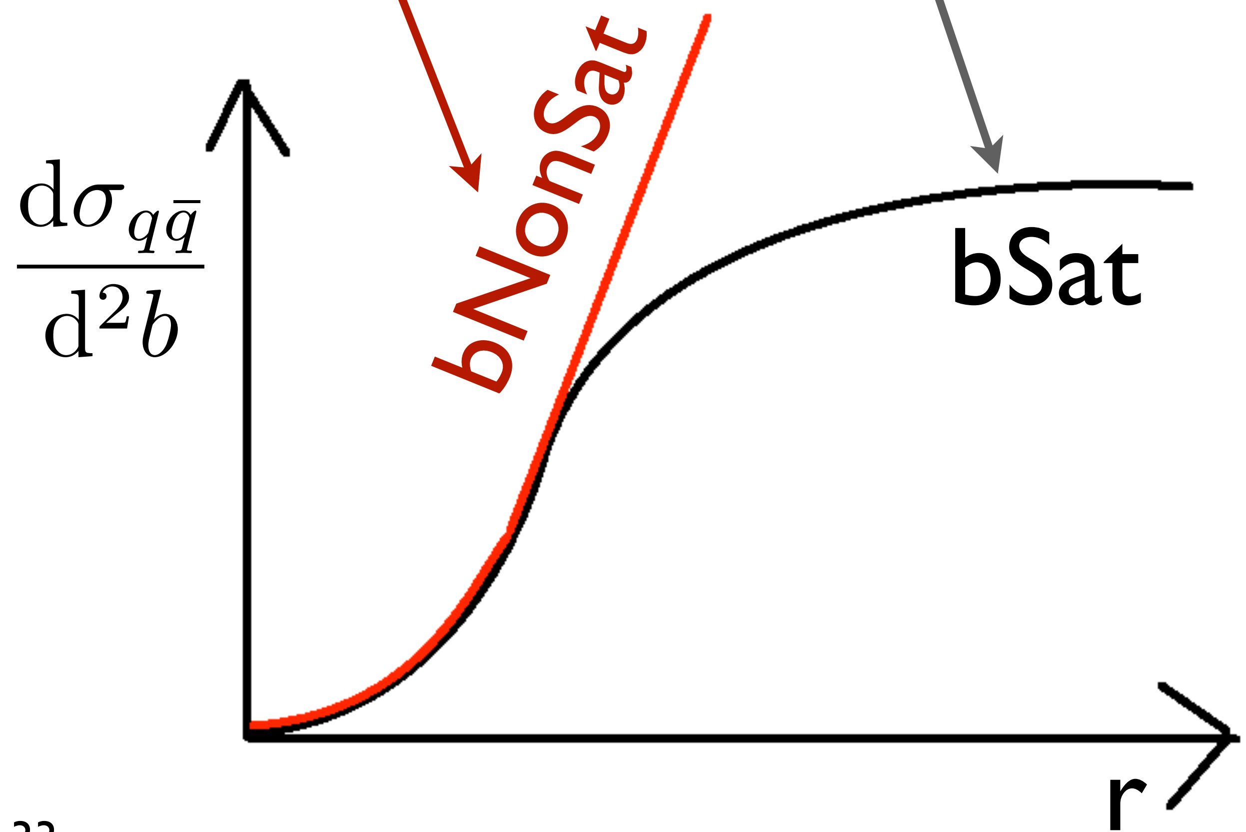
bSat and bNonSat

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2\mathbf{b}} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x,\mu^2) T(b)\right)\right]$$

$$\frac{\mathrm{d}\sigma^{\mathrm{nosat}}_{\mathrm{q\bar{q}}}}{\mathrm{d}\mathbf{b}} = \frac{\pi^2}{N_C} r^2 \alpha_{\mathrm{S}}(\mu^2) x g(x,\mu^2) T(b)$$

Glauber (Woods-Saxon)



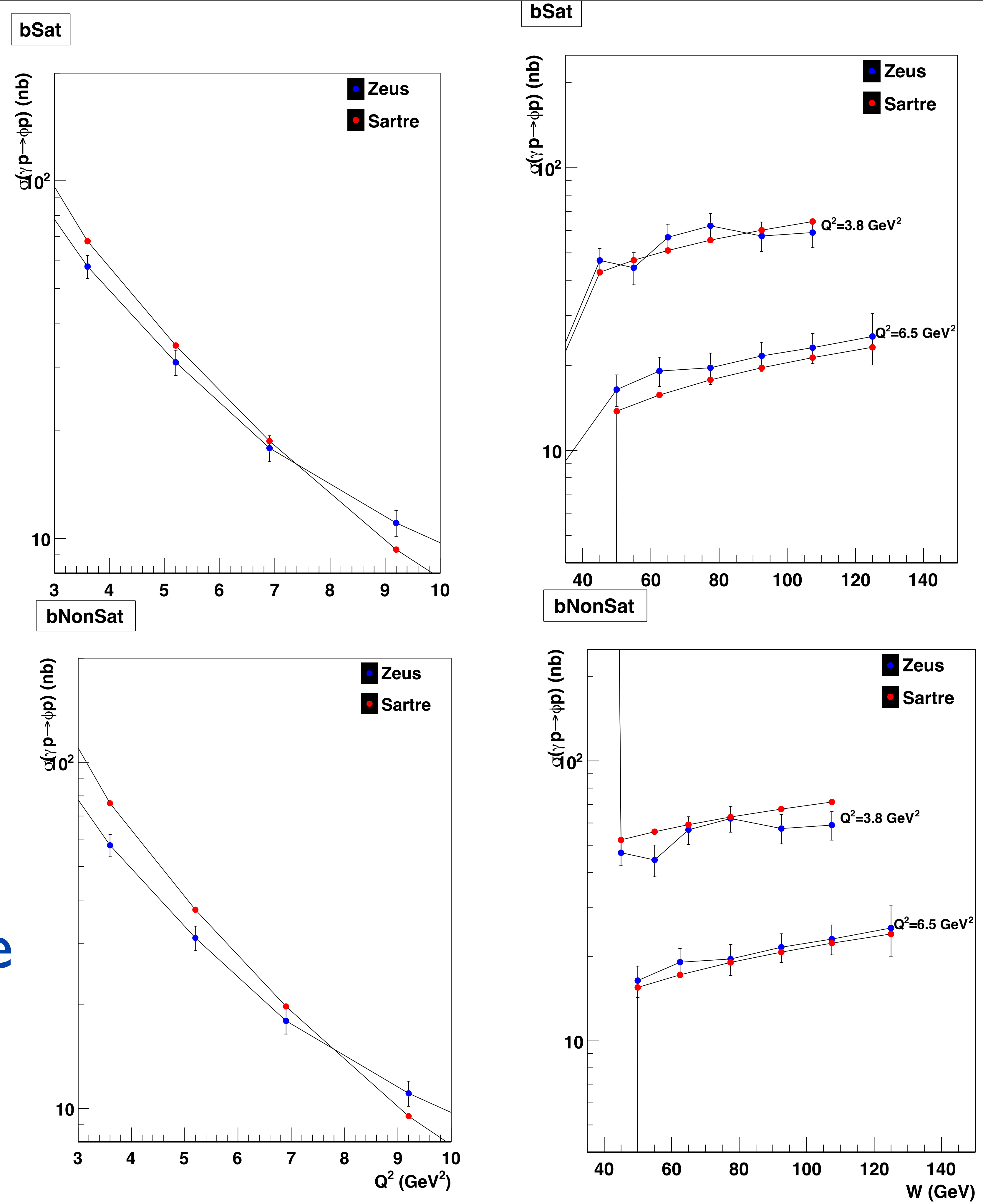


bSat vs. bNonSat at HERA

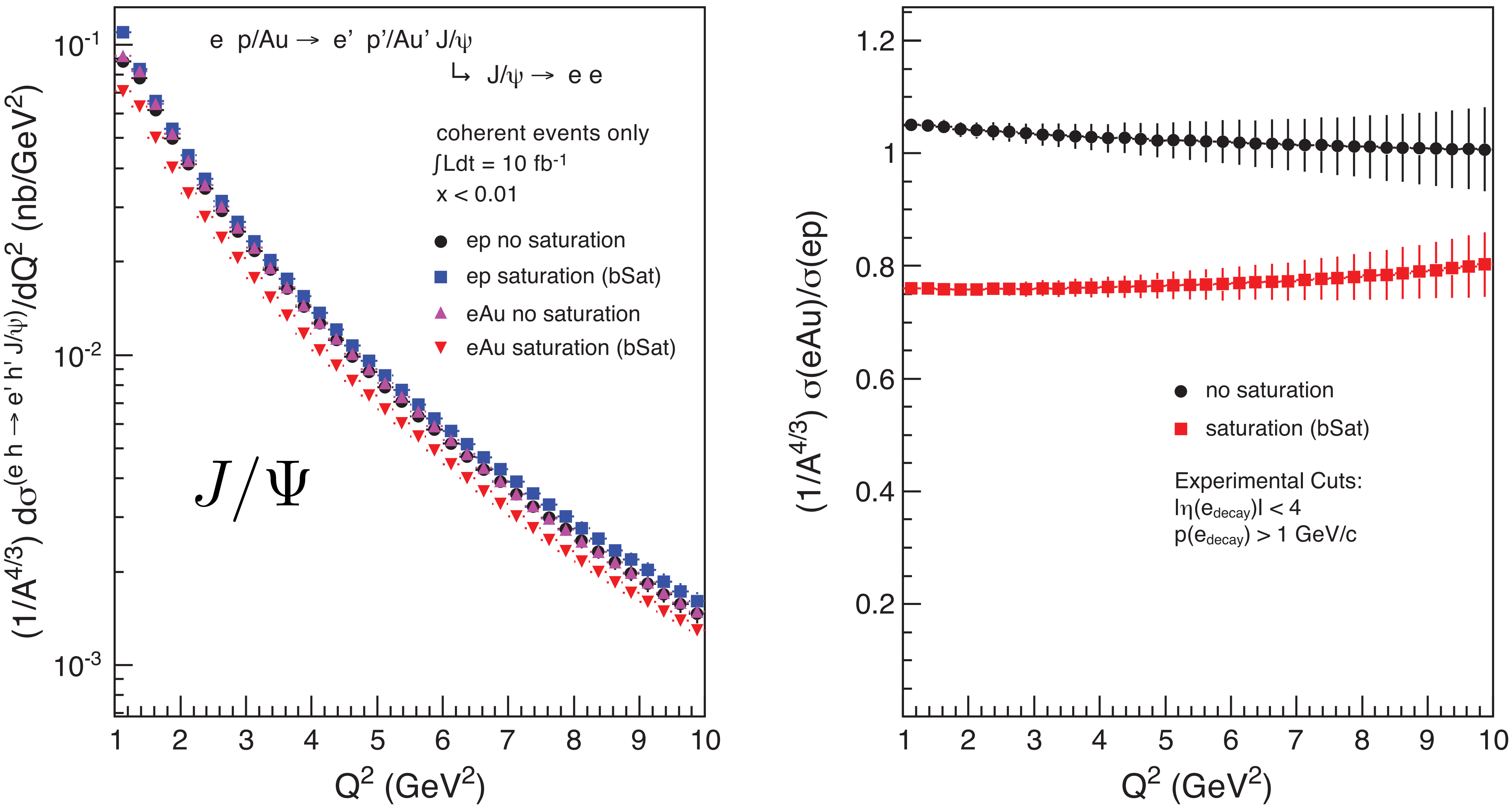
$\phi - \text{mesons}$

No distinguishing power!

eRHIC can probe the difference!



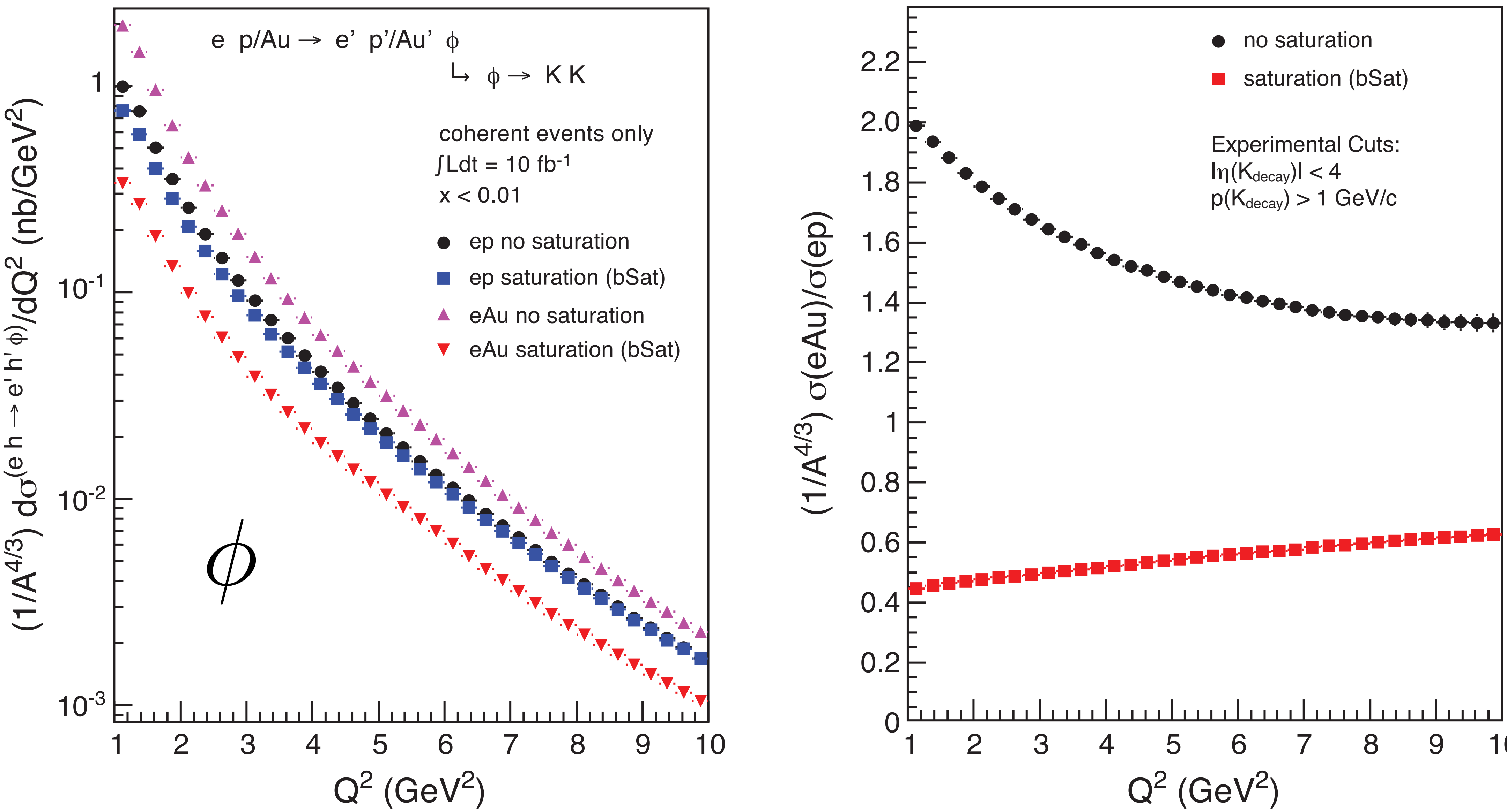
eRHIC predictions:
Exclusive diffraction Sartre



Can constrain models a lot with a few months of running!

High precision over a large range in Q2!

eRHIC predictions: Exclusive diffraction Sartre



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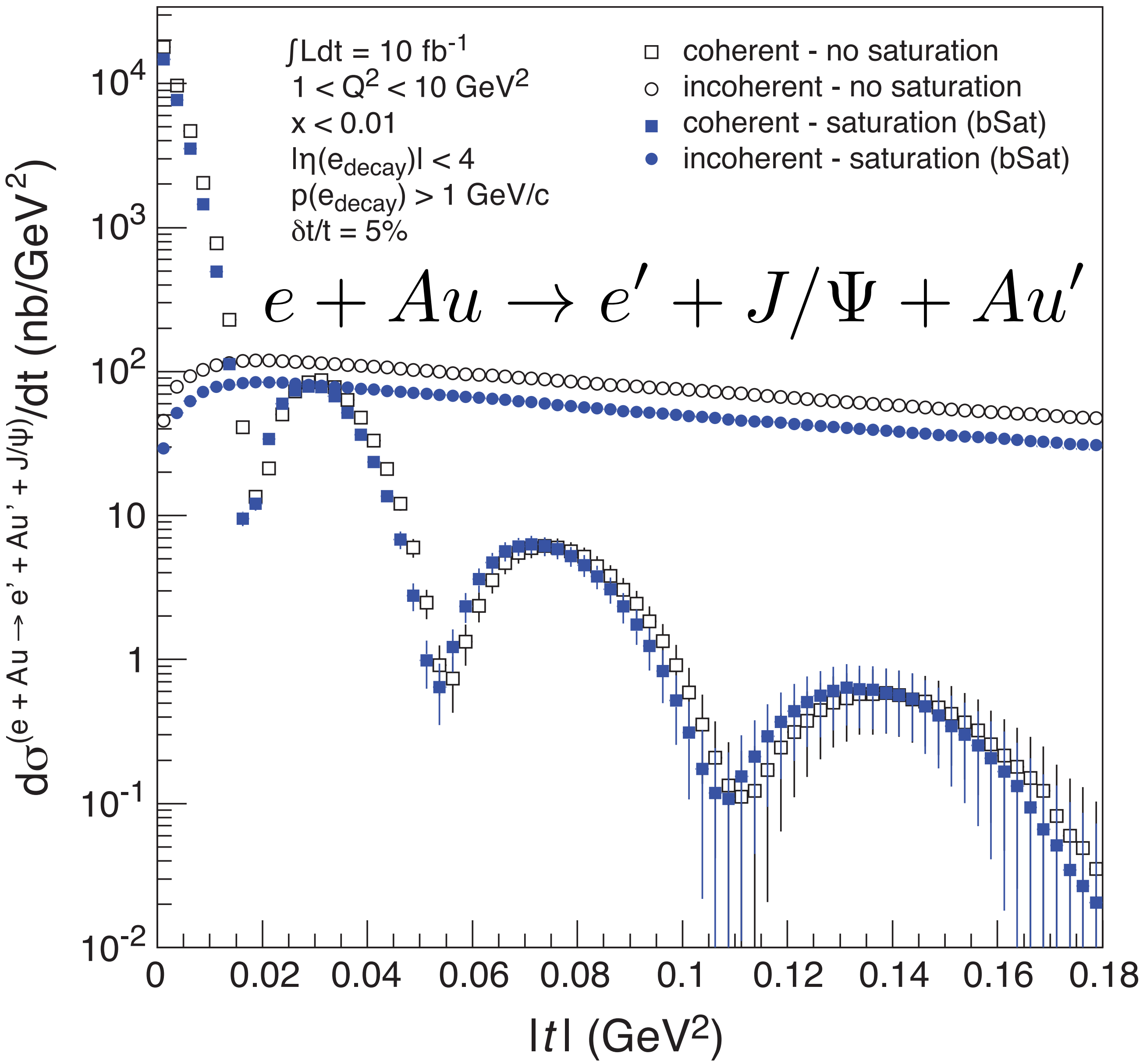
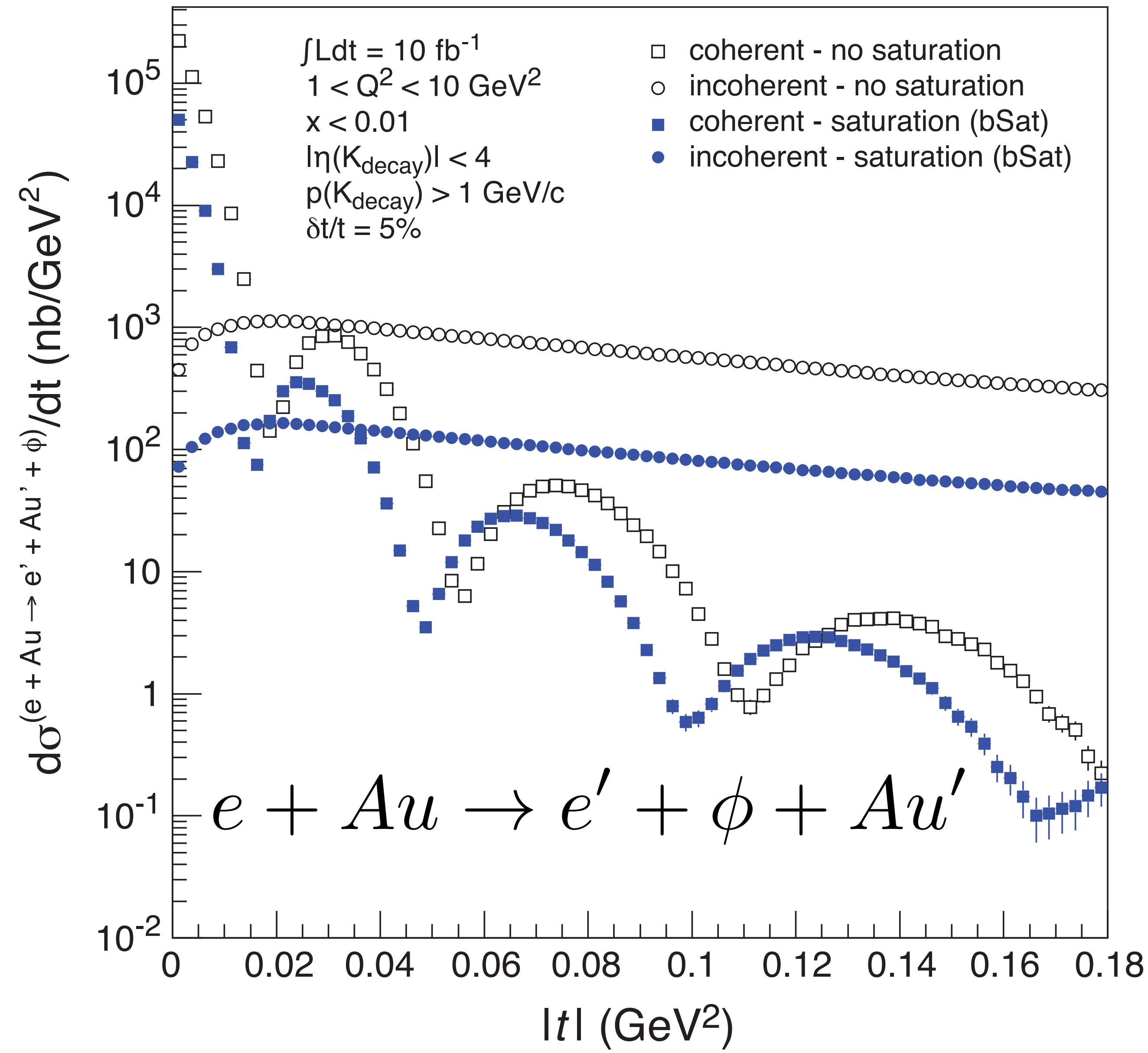
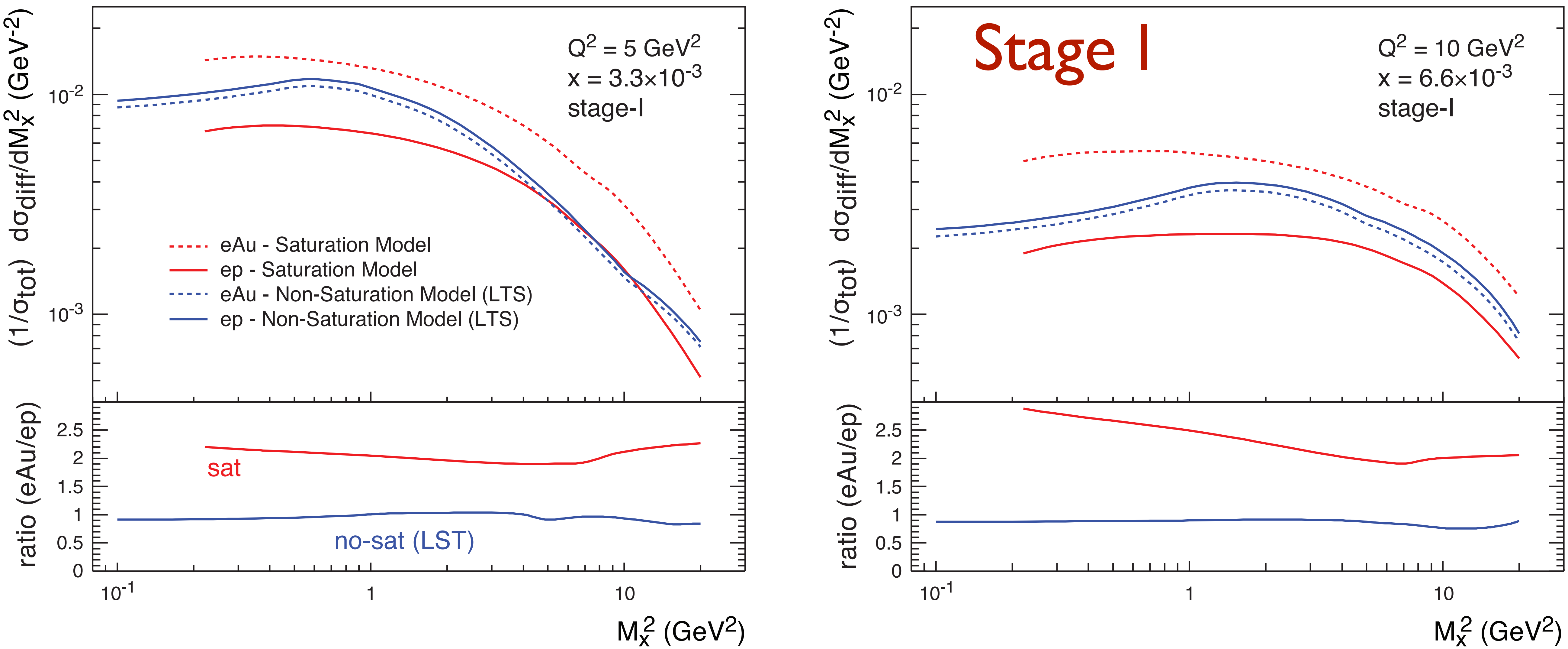




Can constrain models a lot with a few months of running!
First 4 dips obtainable.

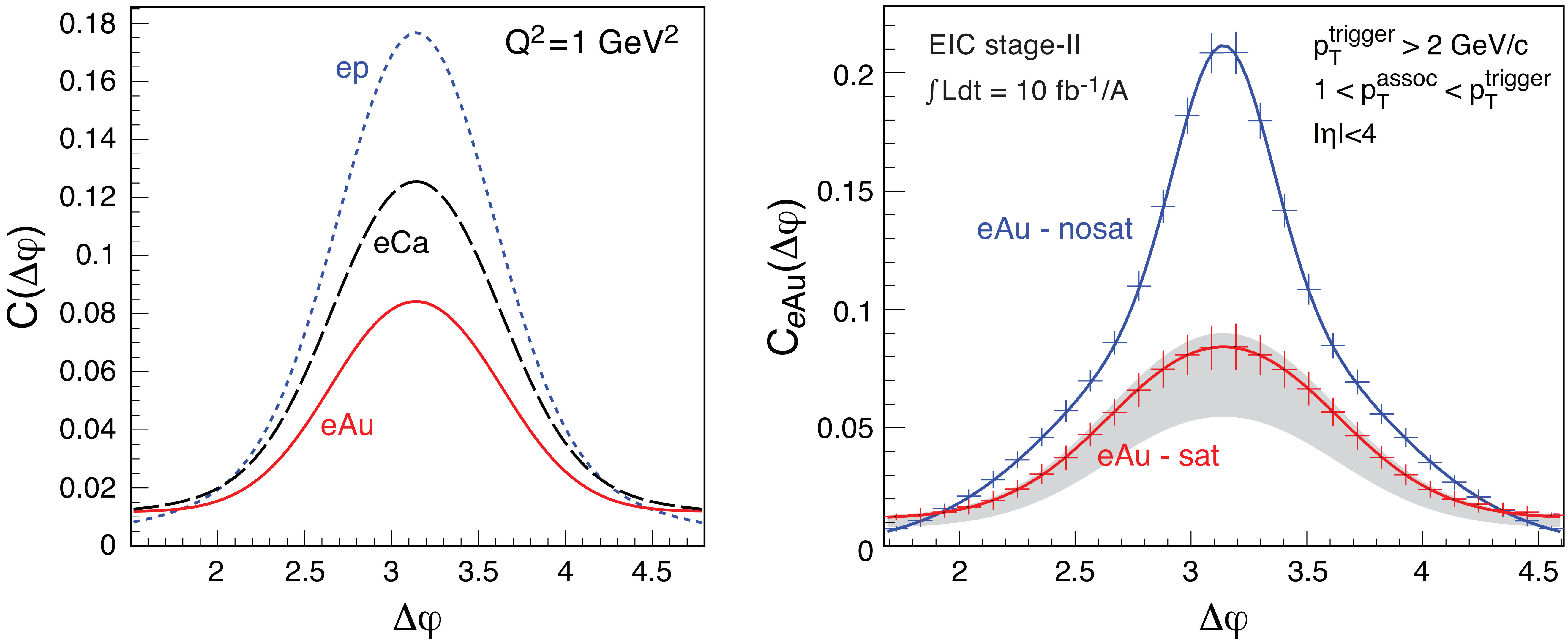
eRHIC predictions: Inclusive diffraction



Can constrain models a lot with a few months of running!

Already in Stage 1!

eRHIC predictions: Dihadron correlations, away peak



Can constrain models a lot with a few months of running!

Summary

To understand many properties at of heavy ion collision one must have a detailed understanding of the initial conditions of the ions.

eRHIC is a perfect environment to measure the initial condition at high precision.

eRHIC will open up a new regime for saturated QCD.

eRHIC will be an ultra high resolution femtoscope!

What we learn from diffraction:

Obervable	Process	What we learn	Coh./Inc.
$\sigma_{diff}/\sigma_{tot}$	Inclusive	Level of saturation	Coherent
$d\sigma/dt$ No breakup	Exclusive	Spatial gluon density $\rho_G(\mathbf{b})$, important for e.g. η/S	Coherent
$d\sigma/dt$ Breakup	Exclusive	Fluctuations and lumpiness of gluons in ions	Incoherent
$d\sigma/dt$	Exclusive	Level of saturation	Coherent & Incoherent
$\Delta\Phi$ of dihadrons	DIS	Level of saturation vs. shadowing	

Detecting Nuclear Breakup

- Detecting **all** fragments $p_{A'} = \sum p_n + \sum p_p + \sum p_d + \sum p_\alpha$ ... not possible
- Focus on n emission
  - Zero-Degree Calorimeter
  - Requires careful design of IR
- Additional measurements:
  - Fragments via Roman Pots
  - γ via EMC

Traditional modeling done in pA:

Intra-Nuclear Cascade

- Particle production
- Remnant Nucleus (A, Z, E*, ...)
- ISABEL, INCL4

De-Excitation

- Evaporation
- Fission
- Residual Nuclei
- Gemini++, SMM, ABLA (all no γ)